

Using the Practices of Science in Elementary Schoolyard Inquiry Investigations

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Dedication

To my family, Dave, Aaron, Ana, Mom, Alyssa and Hans for your ongoing love, support,
and patience, and in memory of my father, John.

Abstract

The goal of this study was to explore how elementary students engage with and make sense of the practices of science when involved in authentic scientific investigations guided by student-generated questions. Since communication and collaborative work are inherent in the practice of science, the study used students' in and out-of-class interactions and discourses to understand more about how elementary students engaged in the practices of science (PoS). Whole-class discussion, small-group discussion, and written artifacts were analyzed using qualitative methods to discover the types of discussions students engaged in, the levels of the rigor of the discussions, and the purposes of the different contexts for the enactment of the practices (Kelly, 2014).

In order to answer the research questions related to elementary students' ways of participating in various practices of science (PoS) such as observation, experimentation, argumentation, and collaboration, the researcher used qualitative case study methods. These methods included in-and-out-of-class observations, student artifacts, audio recordings of students' conversations and discourses during peer-to-peer, whole class, and student-teacher interactions, and informal conversations with students and the teacher. The data were analyzed using constant comparative methods whereby generating themes that captured broad as well as specific nature of ways in which students and teacher interacted with PoS.

The analysis of the data showed that peer-to-peer discussion was central to inquiry pedagogy and learning and practicing the PoS for understanding science. The students benefitted from models of PoS to both get familiarized with the PoS and later replicate those in their learning. Similarly, small group interactions seemed to provide more opportunities for students to speak and use the language of science in a non-threatening environment. This environment allowed for students to share their ideas more openly and frequently.

This research would contribute in the areas of student engagement in science practices, teacher's role in promoting PoS in science teaching and learning, curriculum development with a focus on PoS, and linking citizen science with PoS to improve everyday understandings of science. Additionally, this study could add to the understanding of the importance of local problems as authentic local contexts to learn about PoS including the skills of design solutions. The broader impact of this study may be in student involvement in citizen science projects, local environmental justice projects, and school community projects.

Keywords: Inquiry, Practices of Science, schoolyard investigations, science discourse

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Abbreviations

NRC	National Research Council
POS	Practices of Science
D2D	Driven to Discover
GSP	Great Sunflower Project
GRR	Gradual Release of Responsibility

Chapter 1:

Introduction

Rationale

Children are naturally curious about the world. They ask questions, notice the sights and sounds of their environment, and test out materials and phenomena in their environment to understand how the world works (National Research Council [NRC], 2000). In other words, children informally use scientific and engineering practices in their daily work and play (NRC, 2000). Elementary science education is challenged to engage children's inherent interest in science and engineering in formal school settings and to align science instruction with the professional practices of science and engineering. When science is taught at the elementary level, lessons often emphasize "final form" science (Duschl, 2002), a positivist (Driver, Newton, & Osborne, 2000) approach, also called "cookbook science" (Dunbar, 1995). Final form, positivist science depicts science as permanent and fixed rather than a dynamic endeavor seeking to understand the way the world works. Additionally, in response to national concerns about student performance in United States public schools, high-stakes reading and math tests in elementary school begin as early as third grade (Linn, Baker, & Betebenner, 2002) and classroom testing for leveling or differentiating begins as early as kindergarten (Dodge, 2009). As a result, time devoted to reading and math instruction usurps science and social studies time (Milner, Sondergeld, Demir, Johnson, & Czerniak, 2012). So, despite children's inclination to engage in scientific thinking, elementary school children in the United States are thrust into a competition to read, write, and learn mathematics at predetermined benchmarks

limiting opportunities for them to engage in the practices of science.

The emphasis on final form science and reading and math in the classroom precludes opportunities for students to engage in authentic science inquiry investigations. To engage K12 students to authentic science instruction, the National Research Council (NRC) (2012) in their report, *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*, established critical components for K-12 science instruction in response to the society's increasing needs for experts in the areas of science and technology. One-third of the framework details science and engineering practices, which I hereafter refer to as "practices of science" (POS). These practices of science, listed in Table 1.1., include: "writing questions and defining problems, developing and using models, planning and carrying out investigations, analyzing and

Table 1.1

National Research Council Practices of Science and Engineering, 2012.

Practices of Science
1. Writing questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematical and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence and obtaining
8. Evaluating, obtaining, and communicating information

and interpreting data, using mathematical and computational thinking, constructing explanations and designing solutions, engaging in argument from evidence and obtaining, evaluating, and communicating information” (NRC, 2012, p. 49). Science and engineering practices immerse students in authentic questions and problems, and characterize more realistically how scientists and engineers do their work (NRC, 2012). This emphasis on communication in science is consistent with Gallas’ (1995) application of discussion with peers, “the process of scientific discovery is deeply connected to conversations with colleagues” (p. 14).

The POS in the professional science setting and the classroom occur in social settings and require verbal and written skills to negotiate communication with peers. In the classroom, verbal and written discourse provide evidence of student thinking and learning. I examined student verbal and written discourse to understand student engagement in the science and engineering practices (POS). I use practices of science interchangeably with science and engineering practices. In this study, the use of “discourse” refers to the ways language is used in the realm of science, consistent with what Gee (2014) describes as “big D” (pp. 24-25) discourse. In “big D” scientific discourse, the discourse is based on social and historical interpretations of what science means to those engaged in the discourse. I examine the discourse between peers and between students and the teacher.

In this study, the discourse is analyzed for the purposes of examining students’ understanding of inquiry practices in the science classroom rather than to examine relationships of power as in discourse analysis methodology. Kelly and Chen (1999)

found that high school students engage in verbal discourse for social positioning rather than for science understandings.

Initiatives to engage students in science and engineering practices reach back at least as far as 1903 when Dewey stated, “the essence of science is first-hand experience” (p. 200). Various monikers are used to name the practice of science instruction including: the scientific method, inquiry science, discovery science, and most recently, the practices of science and engineering (NRC, 2012). For the purpose of this paper, I will refer to the process of inquiry (NRC, 2000) as the POS. (NRC, 2012).

Statement of the Problem

A comprehensive elementary educational experience which includes science instruction in addition to other core subjects, prepares children to be responsible citizens, decision makers, and prepares them for meaningful careers. Research describes at least three contributing factors to the limited use of inquiry practices in science education: 1) science instructional time is limited due emphasis on high stakes testing in literacy and math (Carlone, Haun-Frank, & Kimmel, 2010), 2) teachers’ limited exposure and experience teaching science using these inquiry practices results in decreased opportunities for students to engage in inquiry practices (Akerson, Hanson, & Cullen, 2007; Dreon & McDonald, 2012), and 3) similarly, the limited amount of science curricula available to schools and school districts. By engaging in the science practices, students gain experience in understanding the purposes of science and how science knowledge is generated and validated. This study seeks to develop deeper understandings of students’ experiences of using the practices of science based on student-derived

questions in an authentic setting, their schoolyard, to advance their abilities to develop scientific explanations and argumentation from evidence.

Goals and Objectives

The goal of this study is to learn more about how elementary students engage in the practices of science in an authentic scientific investigations guided by student-generated questions. Since communication and collaborative work are inherent in the practices of science, the study used student communication to learn more about how elementary students engaged in the practices of science. Whole-class discussion, small-group discussion, and written artifacts were analyzed to discover the types of discussion students engaged in, the level of rigor of the discussion, and the purposes of the different contexts for student enactment of the practices (Kelly, 2014). The goals and objectives of this study lead to the following research questions.

Research Questions

Research Question 1: How do elementary students engage in the practices of science while conducting an inquiry investigation?

Research Question 2: What practices of science are observed in (a) peer-to-peer interactions, (b) whole class instruction, and (c) written artifacts in science notebooks and posters during an inquiry investigation?

Potential Significance

Elementary students have the capacity to engage in the POS to learn more about the world around them (Duschl, 2007). Elementary students are developmentally capable of engaging in investigations in authentic settings to ask questions, carry out

investigations, analyze data, construct explanations, and communicate their findings using the POS. Elementary teachers and schools emphasize literacy and math instruction in response to high-stakes testing in those content areas and incidentally reduce the time and emphasis on science education. Few elementary teachers, when they were students in classrooms, learned science in an inquiry-based classroom. Thus, they engaged in the practices of science as the method of scientific inquiry rather than as an instructional method with webbed connections among the practices. The theory of “apprenticeship of observation” (Lortie, 1977) suggests that teachers teach as they were taught rather than using inquiry methods taught in teacher preparation programs. Teachers also find science instruction time-consuming in a climate of high-stakes testing in math and literacy (Carlone, et al., 2010). Providing opportunities for students to learn using the POS can support their understanding of how science is done and also may influence them in their future teacher career.

Overview of the Following Chapters

Chapter two presents a review of the literature. The literature section presents relevant works from science education research and policy documents. The chapter begins with the study’s theoretical frameworks, inquiry-based instruction, and socio-constructivism. This chapter also discusses the literature on the practices of science and the nature of the discourses in elementary science education.

Chapter three describes the qualitative research study design, methodology, methods of data collection, and analytic processes. This chapter also articulates why qualitative methodology and related data collection processes were suitable to answer the

research questions on students' POS experiences in an elementary classroom.

Chapter four examines the results relative to the research questions. This chapter presents detailed and nuanced analysis of the findings. This chapter presents 1) the relevance of peer-to-peer discussion while students are engaged in the POS, 2) impactful features of whole-class discussion to teach POS, and 3) observations on the nature of POS when used to guide students to complete investigations.

Chapter five presents discussions of the results and the implications of the study. The discussions and implications link prior research and potential teacher actions in the classroom teaching. This chapter also presents potential future works in the areas of science education to enhance science teaching and student learning.

Chapter 2:

Literature Review

This study seeks to understand elementary students' capacity and use of whole-class discussion, small-group discussion, and written artifacts to engage in the Practices of Science (POS) in a pollinator investigation in their schoolyard prairie. Specifically, students will develop authentic questions based on their observations of pollinators in the schoolyard prairie to engage in investigations using the POS. Much of the literature on the POS relates to the capacity of teachers and pre-service teachers to teach the POS in the elementary classroom but the focus of this study is to understand elementary students' capacity to use the POS to understand more about the pollinators in their schoolyard prairie in a whole-class and small-group investigations by examining the data from whole-class discussions, small-group discussions, and written artifacts.

For this chapter, I reviewed the literature relevant to this research. I begin by discussing the theoretical frameworks of inquiry and its connections with socio-constructivist learning theories. Secondly, I examine the historical use and challenges of inquiry and the POS in elementary science classrooms. Finally, I examine the ways students interact in the elementary classroom specifically when engaged in the practices of science, specifically through whole-class discussions, small-group discussions, and written artifacts.

Theoretical Frameworks

The theoretical frameworks for this study are inquiry and socio-constructivism. In this section, I define and describe how these frameworks relate to this study. I begin by

providing a brief historical summary of inquiry and a discussion on inquiry as an instructional method in science education. This section concludes with inquiry as a theoretical framework in this study.

Inquiry instruction. Inquiry instruction has been a recommended method for teaching science, promoted by Dewey as early as 1903, then was rebranded as discovery learning by Bruner in 1961, and more recently endorsed by the American Association for the Advancement of Science (AAAS) in 1990, the National Science Education Standards (NSES) in 1996, and the National Research Council (NRC) in 2012. NRC (1996) defines inquiry as “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (p. 23). In the past, the emphasis was on teaching the scientific method, a linear process which emphasized the investigation skills over the practices of modeling, argumentation, and communication (NRC, 2012). The consequence of emphasizing the investigation and its results devalues the “deeper understandings of the concepts and purposes of science,” (NRC, 2012, p. 43).

Dewey (1903) cautioned against the use of curricular materials which rely on rote memorization and are imposed by the head of school. He promoted instructional methods that provided students with opportunities to engage in their own inquiries similar to the way scientists using scientific methods. He supported student engagement in firsthand experiences and student identification of problems or questions leading students to make further observations as a part of a process to solve a problem or an answer the question, in a process much like what was later called the scientific method, then inquiry, or now, the practices of science.

In the 1950s after World War II, the United States established the National Science Foundation (NSF) in response to the United States' competitive endeavors in the space race and other scientific technologies. The goal was to develop a work force of scientists by improving science education to meet these national goals (Duschl, 1990). At the same time the NSF sought to create more scientists, the science community was redefining science (Duschl, 1990) in response to the dynamic nature of scientific knowledge and observational techniques. Discussions about the nature of science began with the early twentieth century Vienna Circle, endorsing "an experiment-driven enterprise" (p. 8) and the hypothetico-deductive method (scientific method) toward a "theory-driven enterprise and model-driven enterprise" (Duschl & Grandy, 2008, p. 8). As the methods for scientific knowledge construction and scientists' processes changed, science instructional methods changed in response. In the 1950s science instruction emphasized what information students knew which changed in the 1980s to emphasize what students can do (Duschl & Grandy, 2008). The new emphasis on what students can do rather than know, aligned with the objectives of inquiry instruction. One of the first supporters of inquiry was Bruner known for promoting a specific type of inquiry, discovery learning. Bruner described discovery learning as a strategy where students 1) seek out patterns and use background knowledge, 2) get motivated by intrinsic rewards, 3) learn problem-solving strategies by engaging in problem-solving, and 4) have greater likelihood to remember ideas they are interested in or they learn in a way that is interesting to them. Bruner's contemporary, Schwab, also advocated for teaching science through inquiry. He emphasized teaching science as a changing body of knowledge

responsive to new discoveries (Barrow,1962).

Levels of inquiry. One of the challenges of inquiry in a highly structured setting like the K-12 classrooms, is the unstructured nature of responding to a student's interests and questions. Teachers need to teach to the grade level standards set by a state but still recognize a student's interests and questions. Additionally, there may be required materials and skills beyond the scope of the elementary classroom that needed to be a part of the inquiry teaching and learning. Banchi and Bell (2008) describe the scaffold of different levels of inquiry on a continuum from structured and teacher-oriented to unstructured and student-oriented with features of structured instruction: question, procedure, and solution. Confirmation inquiry is the most structured level, in which the teacher generates the question, procedure, and solution. The next level is structured inquiry in which the teacher generates the question and the procedure and students find the potential solution (s). In guided inquiry the teacher generates the question and students generate the procedure and solution. Finally, in the most unstructured form of inquiry, open inquiry, the students generate the question, procedure and solution with teacher providing support (Banchi & Bell, 2008).

Critique of inquiry as an instructional strategy. Despite the strong support from the science community for inquiry instruction, there were challenges implementing inquiry as a successful instructional strategy in the elementary science classroom.

Teachers and inquiry. From a technical perspective, teachers lacked experience teaching with inquiry methods because they showed greater commitment to their old curricula that valued memorization of facts rather than the existing inquiry curricula

because the new curricula failed to fill the experience gap. Teachers had limited exposure to inquiry. Many teachers lack experience with inquiry from their own instructional background as a K-12 student (Akerson et al., 2007; Dreon and McDonald, 2012) and potentially as an elementary education major. In a review of inquiry research, Minner et al. (2010) found there is more emphasis on what student teachers should learn and less on teacher strategies. Attempts to disrupt this perpetuating cycle have focused on professional development for reaching preservice teachers and in-service teachers (Lee, Hart, Cueves, & Enders, 2004; Forbes & Davis, 2010; Bhattacharyya, Volk, & Lumpe, 2009).

From a political perspective, teachers lacked in-service instruction and materials to teach inquiry. Due to an emphasis on high stakes testing in literacy and math (Carlone, 2010), literacy and math consume most of the elementary instructional day. Teachers have limited time to teach science, and without in-service instruction and materials, teachers are less likely to teach with inquiry methods.

From a cultural perspective, teachers struggled with assessing inquiry as it was difficult to assess the impact of inquiry on student learning due to poorly defined outcomes of inquiry (Minner et al., 2010). Teachers were also worried they would fail to prepare their students for college and to “cover” all the material in the curriculum (Anderson, 2002).

Students and inquiry. Duschl et al., (2007), pointed out that inquiry is often conflated with hands-on learning (Osborne, 2014) without minds-on engagement: “Students left free to explore, as in pure ‘discovery learning’ approaches, may continue to

face these obstacles, interfering with their ability to learn through inquiry” (p. 271). The NRC framework (2012) addressed this conflation of inquiry by reframing this type of instruction as science and engineering practices. Elementary science curriculum writers limited opportunities for elementary students to engage in the practices of science as a consequence of their inaccurate beliefs that elementary students lacked developmental readiness to engage in the practices of science (Metz, 2008). Writers of *Taking Science to School* (Duschl et al., 2007) debunk this idea and conclude that elementary students are capable of engaging in the practices of science. Metz (2008) highlights the need to integrate the POS at the elementary level. Part of Metz’s argument is that science is inherently messy and using prescribed, hands-on curriculum dilutes the “ill-structured” (p. 142) aspect of science. Upadhyay and Defranco (2008) caution teachers that open inquiry without clear learning goals seemed to confuse students what skills and knowledge they needed to learn but open inquiry had positive knowledge and skills retention effects on students rather than teacher centered teaching. Engaging in the POS with an authentic context provides opportunities for students to define a scientific problem and develop methods to investigate that problem.

Inquiry as a theoretical framework. This research study examined elementary students’ engagement in the practices of science (NRC, 2012) while participating in an inquiry investigation during pollinators in the schoolyard investigative lesson. I used the practices of science as a framework to discuss how elementary students implement these practices in each of the three research settings, whole-class discussion, small-group discussion, and written artifacts.

Socio-constructivist theory. The other theoretical framework for this study is socio-constructivism. In this section, I define and describe socio-constructivism as a theory and how it helps to understand discourse in science instruction. I conclude with a statement describing how the socio-constructivist theory relates to this research study.

Socio-constructivism as a learning theory. The socio-constructivist theory is a learning theory that explains how social interactions and language provide the mechanisms for humans to construct knowledge using contextual norms of a setting (Vygotsky, 1994). This research study is rooted in the theoretical framework of socio-constructivism as it examines elementary students' discourse in science inquiry investigations with a focus on students' engagement in the practices of science. In socio-constructivist thought, learning increases as individuals use language in their thinking. Learning also gets enhanced in dialogues with others as they use language to describe their thought processes as ideas (Vygotsky, 1994).

Socio-constructivism in science education. Science education researchers recognize the importance of socio-constructivism to explain the role of background knowledge, language, and discussion in learning science. This also supports students to make their ideas about science clearer. Driver (1994) described a scenario in which middle school students used discussion and their preconceived ideas about the three states of matter. The students collaboratively developed their thoughts into a more elaborate theory about the relationship between the moving particles, temperature, and energy. This example illustrates the importance of social settings in science learning and confirms that "facts are socially constructed" (LaTour & Woolgar, 1979, p. 169-170). Since inquiry

practices are collaborative efforts, students use language in classroom and peer-to-peer discussions to think-aloud, question their understandings, and proposes scientific explanations.

As mentioned above, language as a part of the culture of the classroom plays an important role in the socio-constructivist theory. The practices of science use language (Cavagnetto, 2010) for metacognition, critical reasoning, interpretation of findings (*Constructing Explanations And Arguing From Evidence*), and knowledge construction within dialogical interactions. Scientists are dependent on language to generate scientific explanations, argue from evidence, and communicate their results with the broader scientific community (NRC, 2012).

The use of language is dialogic in science classrooms and occurs in small-group discussions, whole-group discussions, and in written communications (Brown & Campione, 1995). The dialogues provide opportunities for “novices [or students] to adopt the discourse structure, goals, values and belief systems of scientific practice[s]” (Brown & Campione, 1995, p. 267).

Impact of teacher and student culture on socio-constructivism in the classroom.

In addition to their preconceived ideas about science, students and teachers also bring their prior experiences, home language, and culture to the classroom. Bakhtin, a Russian social scientist, and Vygotsky shared similar ideas of the socio-constructivist nature of knowledge acquisition (Marchenkova, 2008). Culture was at the core of Vygotsky and Bakhtin’s theories, and they both described the importance of the speaker and the speaker’s awareness of the listener (Marchenkova, 2008). Bakhtin recognized that

students bring social languages based on their home culture to school with them and those influences converge with the social languages of the classroom (O'Loughlin, 1992). While students bring multiple social languages to the classroom, teachers also bring their own social language to the classroom, which tends to be "a very uniform speech genre of formal instruction" (Wertsch, 1991, p. 111). O'Loughlin (1992) examined the socio-cultural construction of knowledge in the classroom by examining a teacher's power to privilege some student voices over others, and often the teacher favored a familiar voice, the middle-class lens shared by the teacher (Delpit, 1986, 1988; Edwards & Mercer, 1987). Edwards and Mercer (1987) determined that the teachers controlled the environment and consequently, the knowledge constructed in the classroom as "privileged and authoritative" (O'Loughlin, 1992, p. 806). Delpit describes this environment as the "culture of power," an environment that favors middle-class children and influences the cultural interpretation of knowledge in the classroom (1988).

Socio-constructivism as a theoretical framework. In this study, socio-constructivism provided a framework for examining the critical role language played in helping students make meaning from their inquiry investigations while engaged in the practices of science during whole-class discussion with their teacher, small-group discussions with their peers, and written artifacts to produce evidence of individual and group thinking.

In the next section, I review the NRC (2012) definitions of the Practices of Science and Engineering (POS) and then examine science education literature relative to each practice of science. The POS are important to my study as they reflect the current

iteration of scientific inquiry in science education. In response to disparate and diffused definitions of inquiry, the current emphasis lists and defines the practices of scientists and engineers (Abd-El-Khalick et al., 2004).

National Research Council Practices of Science

In 2012, the National Research Council (NRC) published *A Framework for K-12 Science Education*, as a guide for creating national science and engineering standards. The national standards framework is a three-dimensional framework that integrates scientific practices, scientific ideas, and science content that crosses all scientific disciplines to provide a wholistic science curriculum. Specifically, the three dimensions are the Practices of Science and Engineering (POS), Crosscutting Concepts, and Disciplinary Core Ideas. “The *Framework* specifies that each performance expectation must combine a relevant practice of science or engineering with a core disciplinary idea and crosscutting concept appropriate for students of the designated grade level” NGSS, 2013, Appendix F, p. 1). The Practices of Science and Engineering elaborate on investigation to include the skills of explanation, argumentation, and communication with an intentional effort to recognize the value of developing and using models to expand scientific understandings. The POS are integral to my research as elementary students use the POS to engage in inquiry investigations. The POS are listed in Table 1.1. and definitions and research literature on each of the practices are below.

Asking Questions And Defining Problems. Questions are at the heart of science: “[T]he ability to ask well-defined questions is an important [aspect] of science literacy” (NRC, 2012, p. 54). Inquiry investigations are opportunities for students to develop their

own questions and procedures to collect data for creating explanations and arguments to defend their results (Duschl et al., 2007).

Careful observations lead to questions, but not all questions lend themselves to scientific study (Strauss et al., 2017). To drive an investigation, students' questions need to generate measurable evidence, a scientific model, or an explanation (NRC, 2012).

Pearce (1999) uses the term, testable questions, and defines them "as questions students can answer on their own through direct observation or by manipulating variables in an experimental setting" (pp. 12-13).

Teacher strategies to support students' testable questions. To help students develop testable questions, Pearce (1999) uses a "Question Search" (p. 13) activity in which students choose one object from a collection of many objects to describe, draw, and then generate as many questions as possible about the object. When the observation is over, students share their observations with the class and students discuss how these observations may develop into a testable question. In his "More Testable Questions" (p. 15) activity, Pearce (1999) supports students to turn their "can I?" questions into "is it possible to...?" (p. 15), or into quantifiable questions such as, turning "can I use a magnet to pick up paper clips?" into "how many paper clips will it pick up?," or finally writing comparison questions such as, "which magnet will pick up more paper clips magnet A or magnet B?" (p. 15).

Similarly, in the Driven to Discover (D2D) professional development curriculum guides, Thompson et al., (2018) discuss how to help students generate questions through observations of a natural phenomenon. The D2D curricula are written for pollinators,

birds, dragonflies, and phenology studies. Observations take the form of questions and ‘I wonder’ statements based on observations of pollinators, birds, dragonflies, and phenological data. Students are guided to sort the questions into four categories 1) look it up, 2) not answerable, 3) testable but not practical, and 4) testable (Thompson et al., 2018, p. 4-14). Once students learn what makes a testable question, they are encouraged to convert their non-testable questions into testable questions (Thompson et al., 2018).

Roberts (1996) developed the following teacher strategies to support elementary students as they develop research questions: 1) listen to their observations and explorations, 2) keep track of the questions in journals, science notebooks, or classroom charts, 3) call attention to inconsistencies in their investigation results, 4) use classroom discussions to identify new approaches to problems and analyze the pros and cons of these approaches, 5) help students map research strategies, 6) discuss ethical and practical problems, and finally, 7) introduce students to new scientific techniques. There is considerable overlap between Roberts’ (1996) teacher strategies and the D2D curriculum teacher strategies as both build off and record student observations, use classroom discussions to identify problems in investigation planning, discuss ethical and practical problems, map research strategies, and introduce new techniques.

Developing And Using Models. As students begin to understand scientific concepts, they may develop mental models to represent their observations. These mental models become conceptual models when students make drawings, diagrams, physical representations or mathematical representations of their mental models (NRC, 2012). These conceptual models represent explanations of scientific thinking about a scientific

topic but differ from the actual object with inherent limitations as they highlight certain features more than others as an instructional or communication tool (Osborne, 2014). Models serve as epistemic tools to communicate “knowledge of specific features of science *and* their role in contributing to how we know what we know” (Osborne, 2014, p. 184).

For younger students, models are representations such as replicas or diagrams but for older students models may be mathematical representations and abstract models. At the K-12 level, models are used to represent quantities, show similarities and differences, or a physical model of a proposed object in engineering. In grades 3-5, students build on those uses and add building models or drawing diagrams that propose design solutions, show relationships among variables, make a prediction, or test a cause and effect relationship. In a study, third graders created model-based explanations of plants and plant processes to show their epistemic thinking of “How do I know? and Why do I believe?” in constructing explanations (Zangori & Forbes, 2016, p. 963). Students were prompted to create drawings to show the important things that happen to seeds when they grow and why those things happen. In this case students looked for answers to questions such as what a seed needs to grow into a plant and ways to use numbers or labels where appropriate. Researchers evaluated the models by looking for evidence of components included, like, sequencing, explanatory processing, mapping, and representation of the underlying science principles.

Incorporating student-developed models into inquiry instruction is a new addition for many elementary science teachers. Traditionally models were used as an instructional

tool or were pre-determined by the teacher or curriculum. The NGSS POS expectations require students to use models as explanatory tools that make connections to broader scientific understandings.

Planning And Carrying Out Investigations. After developing investigable questions, students are ready to plan and carry out an investigation. In *Planning And Carrying Out Investigations*, students need to “state the goal of the investigation, predict outcomes, and plan a course of action” (NGSS, 2013, p. 7). Scientists’ investigations allow them to test their ideas and develop theories about how the world works (NRC, 2012). An important part of planning investigations is identifying the variables being tested or the independent variable, and the response variable being measured or the dependent variable (NRC, 2012). By the end of the fifth grade, students should be able to control variables and design a fair test in a controlled experiment (NGSS, 2013). In a field observation, they need to determine how to collect data in a setting where they cannot control all the variables. Students should also be able to determine the appropriate sample size and number of replications.

Analyzing And Interpreting Data. After generating data from investigations, students analyze and interpret the data to understand what their data mean. Scientists and K-12 science students use tools for “tabulation, graphical interpretation, visualization, and statistical analysis” (NRC, 2012, p. 51) including digital tools. Students analyze and interpret data to seek patterns and trends and use mathematical and other representations to give a cohesive meaning to these patterns and trends. The key in analyzing and interpreting data is that students should see data as giving evidence to support findings in

science and engineering (NGSS, 2013). In other words, students need to learn that graphs are pictures that tell the story of their investigation results.

One supportive tool for guiding students in making sense of data in the form of graphs, is the The Biological Sciences Curriculum Study (BSCS)'s effective strategy, The Identify and Interpret (I²) Strategy, to guide students in data analysis and interpretation. I² is a step-by-step strategy instructing students to identify patterns and trends, interpret what those trends mean in the context of the study, and then write a descriptive analysis of those trends as evidence to support their findings.

Using Mathematics And Computational Thinking. Mathematics and computational thinking are tools used to analyze and interpret data. They are used for “constructing simulations, statistically analyzing data, and recognizing, expressing, and applying quantitative relationships” (NRC, 2012, p. 51). Mathematics is used in science to represent physical variables and construct a mathematical relationship between the variables (NGSS, 2013). Mathematics can also be used to make predictions and determine the significance of scientific findings (NRC, 2012). Sneider, Stephenson, Schafer, and Flick, 2014 described computational thinking as “approach[ing] a new situation with an awareness of the many ways that computers can help them visualize systems and solve problems” (p. 2). In science, students use math to count, computational thinking to make simulations, programming, data mining from large data sets, and jointly analyzing data or problem solving (Sneider et al., 2014).

By fifth grade students should be able to choose and use tools for quantitative and qualitative measurements, recognize patterns, graph quantities to represent investigation

results, and create and use graphs and charts (NGSS, 2013).

Constructing Explanations And Designing Solutions. In the scientific and engineering practices of *Constructing Explanations And Designing Solutions* (NRC, 2012) students use data to make claims to explain one variable's (or set of variables) relationship to another variable (or set of variables) to construct scientific explanations (NGSS, 2013).

In *Taking Science to School*, (Duschl et al., 2007), an NRC report on the state of science in education, science education researchers and developmental psychologists reviewed the science education literature to summarize four strands of scientific proficiency for K-12 students. The practice of constructing scientific explanations is explicit in the first three strands: “know, use, and interpret scientific explanations of the natural world; generate and evaluate scientific evidence and explanations; and understand the nature and development of scientific knowledge;” (Duschl et al., 2007, p. 36). Thus, clearly showing the value of constructing explanations in learning and doing science.

A model for constructing explanations. In their practitioner literature, Zembal-Saul, McNeill, and Hershberger (2012) use the terms “claims, evidence, and reasoning” (2012, p. 21) to support students to construct explanations and argument from evidence in a heuristic adapted from Toulmin's argumentation model. Toulmin (1958) was a philosopher who developed a “pattern of arguments: data and warrants” (p. 90) to make a claim based on data as evidence. Warrants are the conditions, principles, or laws that apply to a particular claim which can be used to support their claims. In his book, *The Uses of Argument*, Toulmin (1958) provides an example of the claim-evidence-warrant-

rebuttal model:

Harry is a British subject (claim) because Harry was born in Bermuda (evidence) since a man born in Bermuda will generally be a British subject (warrant or reasoning) unless both his parents were aliens or he has become a naturalised American [(rebuttal)(p. 102)].

In *What's Your Evidence? Engaging K-5 Students in Constructing Explanations in Science*, Zembal-Saul et al. (2012) provide the following life science example of claim-evidence-reasoning-rebuttal in response to the question, "Do bush bean plants grow better in direct sunlight?"

Bush beans plants grow better in direct sunlight (claim). The plant in direct Sunlight grew 16 cm, and the plant with less sunlight grew 11 cm. The plant in direct sunlight had 6 leaves, and the plant with less sunlight had 3 leaves. Finally, the plant in direct sunlight was a dark green and the plant with less sunlight was pale green (evidence).

Height, number of leaves, and color are all important indicators of a plant's health. Since the plant in direct light was taller, had more leaves, and was dark green, that means it was able to grow better (reasoning).

On day 2, the plants looked the same, so you might think that light does not matter.

But after 2 week, the height, leaves, and color were different (rebuttal). (p. 30).

Zembal-Saul et al., (2015), encourage the use of claim-evidence-reasoning model to teach children how to both question their peers' scientific explanations and to respond

to challenges to their reasoning. In doing so, students develop a scientific habit of mind (Driver, 1994). This format also promotes students to use the disciplinary language in their investigation to frame their claims, evidence, and reasoning (Zemba-Saul et al., 2015) as scientists do in the real world (Duschl et al., 2007). These disciplinary language tools develop students' ability to understand how scientists use evidence to propose new theories through their scientific investigations (Sandoval & Reiser, 2003; Duschl, 2007).

Elementary students need explicit instruction to develop scientific explanations using claims and evidence and instruction needs to respond and adjust to students' misconceptions throughout the lesson (Zangori & Forbes, 2016). Additional support is required to move students beyond explications which connect claims and evidence to developing explanations that explicitly connect to science content (Zangori & Forbes, 2016).

Engaging In Argument From Evidence. The practice of engaging in argument from evidence is very similar to constructing explanations. I have separated explanations and argumentation in this literature review to align with the practices of science (2012). These two scientific practices are complementary since while students develop explanations, they begin to create arguments and defend their explanations in their thinking and in their discussions with peers (Berland & Reiser, 2009). In their work with student discourse and science meaning-making, Hogan, Nastasi, and Pressley (1999) refer to using explanations and argumentation as one practice called "knowledge building." Appendix F (NGSS Lead States, 2013) shows how argumentation is different from constructing explanations by defining argumentation as a "process for reaching

agreements about explanations” (p. 13). When students are engaged in argumentation from evidence, they analyze data and develop claims to summarize their results. They present their results to their peers who question their claims and suggest alternate explanations or procedures to strengthen the scientific reasoning based on the strength of the evidence (NSES, 1996).

Argument, as used in science and science education, relies on the argumentation theory of Toulmin, discussed earlier in the *Constructing Explanations And Designing Solutions* practice. Toulmin’s model of argumentation which has been adopted by other science education researchers (Kelly & Chen, 1999; Jiménez-Aleixandre, Bugallo, & Duschl, 2000, Zembal-Saul et al., 2012).

Here I want to describe the fourth strand from the *Taking Science to School* framework. Strand four states that K-12 science students should be able to “participate productively in scientific practices and discourse” (Duschl et al., 2007, p. 2) where by their argumentation is supported by the evidence at hand. “The goal of those engaged in scientific argumentation is a common one: “to tease out as much information and understanding from the situation under discussion as possible” (Duschl et al., 2007, p. 33). In his defense of the NGSS science practices, Osborne (2014) states the two goals of argumentation as a science practice is first, the importance of developing students’ metacognition of science knowledge and secondly for them to observe the variety of argumentation types. Schwab suggests another purpose of argumentation as “revisionary” interpretations or questioning that leads students and scientists to the most recent interpretation of scientific discoveries (Schwab, 1958, p. 375).

Argumentation and socio-constructivism. There are three components in scientific argumentation that support the socio-constructive nature of sense-making in science. They are sense-making, context, and disciplinary (content) knowledge.

Sensemaking: Ford (2012) and others (e.g. Wheatley, 1991; Driver, Newton, & Osborne, 2000), refer to argumentation as “scientific sense-making” (p. 208) and emphasize the dialogic nature of sense-making in scientific argumentation. The dialogue occurs both internally and interpersonally as scientists defend the strength of their claims based on the evidence, a feature Ford (2012) calls “oppositional voice” (p. 214). Sense-making aligns the original investigation question with the results to develop scientific understandings.

Context: Secondly, Berland (2012) emphasizes the importance of context, also called framing, to support students’ scientific arguments. Berland and Forte (2012) acknowledge the necessity of aligning argument with their audience and the audience’s critique. “This social dimension to the construction of scientific knowledge has resulted in the scientific community sharing a view of the world including concepts, models, conceptions, and procedures” (Driver, 1994, p. 6). Also inherent in the social aspect of science instruction is the need to develop scientific forms of critique in the process of constructing new scientific knowledge (Ford, 2008).

Disciplinary content knowledge: Finally, students need support and scaffolding to apply the methods and nature of science as they conduct their own research to understand content knowledge. As developing scientists, students have limited, formative knowledge with conducting scientific investigations and science content (Ford, 2008). “In science as

a social practice, critique motivates authentic construction of knowledge that is uniquely scientific.” (Ford, 2008, p. 405).

POS and explanations in elementary science. Due to their complexity, scientific explanations and argumentation are unlikely to occur in student learning without explicit planning and intention (Berland & Reiser, 2009). The snowball phenomenon (Anderson et al., 2001) describes a process by which children learn to argue from reasoning in small group discussion instead of the back and forth talk between teachers and students in whole-class discussion. Anderson et al., (2001) hypothesized fourth-graders would copy their fellow students’ argumentation strategies that were successful in small group discussions, an example of snowballing. More students imitate the successful strategies which leads to the snowball effect as students learn to argue from each other. The snowball phenomenon is a possible mechanism to explain socio-constructivist theories like internalization (Vygotsky, 1994) and participatory appropriation (Rogoff, 1995).

Herrenkohl and Guerra (1998) deepened the quality of student participation in whole-class discussion by giving role assignments to students. Within these assignments, some students prepared questions to analyze their peers’ investigation results such as: “How did you get that? What were your results? ...Did your group agree on the results?” (p. 282). Not only do these questions provide structure and increase student participation, but they also support students in *Engaging In Argument From Evidence* as students shared in constructing and examining knowledge.

Research perspectives on scientific argumentation. In a meta-analysis of argumentation in school science settings, Cavagnetto (2010) identified popular

argumentation instructional strategies like, analyzing discrepant events or science problem scenarios. Cavagnetto (2010) concluded immersion in science experiences, such as using the POS, required students to transfer prior science knowledge correctly at the appropriate time (Cavagnetto, 2010).

Obtaining, Evaluating, And Communicating Information. Communication is vital to the advancement of new scientific findings. Using the tools of mathematics and computational thinking, scientists share their results in professional paper and electronic journal articles, conferences, and books (NRC, 2012) to communicate with broader scientific communities and the general public. Students need to emulate this practice and be able to read, write/produce, and interpret scientific information as clear and persuasive communication. Based on NGSS recommendations, by the end of fifth grade, students should be able to read and understand complex scientific texts and describe how they are supported by evidence, combine written text with scientific information in tables and charts, be able to explain concepts from written texts, and communicate in verbal and written formats. This is an important part of participating in the scientific community.

One powerful example of scientific communication comes from Birmingham et al., (2017) describing a group of urban middle school girls after learning about local environmental problems shared the information with their community. In an informal science club, they studied energy transformations, carbon emissions, and economic implications for their community. Students chose their science teachers as the target audience for their presentation because they wanted the teachers to see how disconnected school science was to students' real lives and demonstrate that science didn't have to be

disconnected to their real lives (Birmingham et al., 2017).

Research on overlapping of the POS. All the POS overlap and intertwine with each other. “The practices are used iteratively and in combination; they should not be seen as a linear sequence of steps to be taken in the order presented” (NRC, 2012, p. 49). As discussed earlier in the inquiry section, the traditional scientific method of the 1950s was considered a linear process. The Driven to Discover (D2D) curriculum illustrates the processes of science diagram as a nonlinear, iterative process (Strauss, et al., 2015). Additionally, in Appendix F of the NGSS, one of the guiding principles of the POS, is “the eight practices are not separate; they intentionally overlap and interconnect” (NRC, 2013, p. 3).

Discourse in science education.

Building on one of the theoretical frameworks for this study, socio-constructivism, this section examines the role of discourse in science education. “Learning is a social activity and is more effective when we are able to discuss our ideas and thinking with others” (Tweed, 2009, p. 112). In the practices of science, verbal and written communication play an important role in science education, including teacher-student discussion, student-student discussion, and written artifacts. In inquiry instruction, “teacher and students explore ideas, generating new meanings, posing genuine questions and offering, and listening to and working on different points of view” (Mortimer & Scott, 2003, p. 39). Teachers use language to provide directions, teach science content, engage in whole-class discussions, listen and response to students answers (Kelly 2014). Students use language to accomplish tasks with other students,

talk about science content, and engage in the practices of science (Kelly, 2014).

Engagement in science discourse leads to deeper science understandings and more sophisticated ways of interacting in settings like science classrooms.

Teacher-student dialogue. Many educational philosophies, such as socio-constructivism, promote the benefits of social interactions and dialogue in learning and building relationships for learning. Teacher-student dialogue in whole-class discussion consists of interactions that occur between the teacher and students. In this type of interaction, the teacher establishes the purpose of the lesson, models a task or skill, and thinks aloud to articulate critical parts of the modeling (Fisher & Frey, 2013). Direct instruction is another way to characterize this type of instruction. Direct instruction is an instructional method to present information and teach skills to many students at one time (Engellmann & Carnine, 1992; Rosenshine, 1997). It is an intentional instructional intervention in which the teacher begins by modeling a skill, then students and teachers practice the skill together, and finally students become more independent with guidance from the teacher. The guidance from the teacher decreases as students demonstrate mastery of the skills. In an instructional demonstration, teachers model expert thinking as the teacher does more than go through the steps but also thinks aloud so students can observe problem-solving in action. This kind of modeling allows students to “apply reasoning when attempting a new skill or concept” (Fisher & Frey, 2013, p. 4).

Thompson et al., (2016) studied student explanatory rigor in discourse and the role teacher responsiveness played in generating productive talk in whole-class discussions. The researchers looked for scientific explanations developed with multiple

students and the teacher using “norm-building and critique” (Thompson et al., 2016, p. 8) but in contrast, they observed discourse in which direct instruction favored “right” answers. Thompson et al., (2016) defined that type of discussion as “pseudo-rigorous” (p. 5). Productive talk in whole-class discussions is based on students’ observations and first-hand experiences to develop rigorous explanations to explain scientific phenomena (Palincsar & Magnuson, 2001).

Peer-to-peer dialogue. Peer-to-peer discussion is an important mechanism for sharing information between students (Rivard & Straw, 2000).

Research on using scaffolds in instruction in peer-to-peer discussion.

Collaborative learning settings, like peer-to-peer discussion, provide environments where students consolidate their thinking and work together to change their thinking consistent with socio-cultural learning theories (Vygotsky, 1994; Dewey, 1903). Learning in these settings may result in some failure, but the hope is that these failures will lead to students paying attention more closely and apply their learning (Fisher & Frey, 2013).

Practitioner research perspectives on argumentation. Cross, Taasoobshirazi, Hendricks, and Hickey, (2008) examined peer-to-peer discourse in argumentation when students discussed science quiz results and the explanations to the quiz answers to more deeply understand the science concepts assessed. Researchers found that students took on different identities in the argumentation such as: a) non-participant avoided scientifically-based comments by mostly repeating what others said, b) argument-initiator made rebuttals and added qualifiers, and c) follower who responded only to prompts posed (Cross et al., 2008).

Zemba-Saul et al., (2013) make several suggestions for increasing productive talk in elementary science students' discussions: 1) remind students of the investigation's guiding question when they take the discussion in a different direction, 2) ask students to look for patterns in the data, 3) ask students what the data means, and 4) ask students how their data relates to the question. Additionally, small group interaction allows students to practice using scientific language and listening to their peers scientific language which supports all students' learning but particularly English language learners (Zemba-Saul et al., 2013).

Huff and Bybee (2013) provided a framework to support student-to-student discourse while engaged in classroom investigation. The framework consists of 1) teaching norms for discussion, 2) focusing on a learning outcome, 3) evaluating best explanations through argumentation, 4) using observations and inference as evidence, 5) teacher helping students identify wrong explanations, and 6) using prior, verified data to support an argument.

Furthermore, talk was important for sharing as students processed their results to generate thinking in productive talk better than in their written artifacts (Rivard & Straw, 2000).

Research on classroom dialogical interactions. As described earlier, most of the research literature (NRC, 2013; Zemba-Saul et al., 2012) focuses on the discourse in whole-class discussion with dialogic questioning between teacher and students. In peer-to-peer discussion, students typically mirror the interaction-response-feedback (IRF) pattern where the teacher actively asks the questions and provides feedback, and the student passively responds (Herbal-Eisenmann & Breyfogle, 2005). Students' learning is

less productive in the IRF model of learning than when they are taught to use a cognitive questioning approach to promote new knowledge in peer discussions (King, 1997).

Elementary students maintain sustained discussion using higher-level thinking skills to explain their understanding in a science inquiry lesson that was not based on IRF model (Gilles, Nichols, Burgh, & Haynes, 2014).

In a study by Rivard and Straw (2000), they found peer-to-peer interaction was an important place for students to generate knowledge. The researchers suspect the reason is that independently, students lacked the scientific background knowledge to construct scientific explanations and they relied on the cumulative knowledge of the group to make explanations. In addition, peer group interactions were important for asking questions, hypothesizing, explaining, and constructing knowledge.

Research of overlapping POS in peer-to-peer interactions. To increase epistemic and social dynamics, Duschl (2008) advocates for creating learning environments that support dialogue to understand student thinking. The goal is to increase student reasoning abilities and motivation, and develop learning assessments to provide students with feedback “and include such things as obtaining and using measurements, data, evidence, models, anomalies, and explanations” (Duschl, 2008, p. 287). Sampson and Clark (2006) reviewed several argumentation assessments to evaluate student scientific arguments and found that it is rare for students to develop persuasive arguments using scientific reasoning on their own.

Written artifacts. Rivard and Straw observed that writing increased knowledge retention overtime but students needed to bring a certain amount of knowledge and have

discussions with peers.

Science notebooks. Science notebooks are common tools used for student writing in science classrooms. Fulwiler (2007) differentiates between the science notebooks for science writing as distinct from journals or logs. Classrooms use journals to teach the process of writing and generally, students choose their writing topic. Scientific logs document records that include detailed accounts investigations whereas science notebooks are a tool designed to teach students “how to think and write about science” (Fulwiler, 2007, p. 26). Students use science notebooks to document each step of the POS (Fulwiler, 2007).

Research perspectives on written artifacts in science education. “The use of writing as an instrument for learning underlines the personal construction of knowledge, whereas the use of talk for learning is consistent with socio-constructivist thought” (Rivard & Straw, 1998, p. 569.)

In whole-class and even small groups, the same students did most of the talking limiting the evidence of student thinking and learning to those students who participated in the discussion. Martin and Hand (2007) suggested one strategy to access all students’ thinking is to collect written student evidence. Zembal-Saul et al., (2010) used writing prompts to scaffold students’ ability to generate claims, evidence, and reasoning for argumentation with the intention that students would internalize the purpose of these scaffolded documents and become more self-reliant.

Drawbacks of written artifacts. Though written artifacts provide documentation from each student, unlike discussion, there are some drawbacks. Students usually

generate written documents during independent work which may prevent or discourage student discussions from prompting deeper and more alternative thinking. Written artifacts may also represent peer or teacher exemplars rather than original thinking from each student. For students with limited language proficiency, written artifacts could generate challenges to complete and express their understandings.

Summary of chapter two and overview of the next chapter

Chapter two outlined the research literature on the theoretical frameworks of the study, inquiry and socio-constructivism, the practices of science, and student communication in inquiry including teacher-student discourse, student-student discourse, and written artifacts. Chapter three introduces the methodology of the research study, including the intervention curriculum, school setting, and the participants.

The literature review provides evidence of the long-term value educators attribute to authentic engagement in science experiences to engage students in ways that simulate the way scientists do their work. Additionally, the review highlights recent trends to support students to develop models to explain their thinking in response to science instruction, construct explanations, and argue from evidence as ways to make connections to the body of scientific knowledge. The review also describes the complementary relationship between the practices of science and student small-group discussions as a venue for engaging in the practices of science.

Chapter 3:

Methodology and Data Analysis

Conceptual Framework of the Study

Research Questions. *How do elementary students engage in the POS while conducting an inquiry investigation?* The supplemental research question is: *What POS are observed in (a) peer-to-peer interactions, (b) whole class instruction, and (c) written artifacts, including science notebooks, during an inquiry investigation?*

Intervention Curriculum

In this study, the fourth-grade classroom teacher was a participant in a two-week summer professional development class funded by the National Science Foundation (NSF; DRL-1417777). The purpose of the professional development was to increase teacher confidence to lead their students in outdoor inquiry investigations using citizen science. Two primary components of the curriculum that teachers learned were: 1) implementing POS instruction in K12 classrooms, and 2) supporting participants to collect and submit data to one citizen science project.

Intervention professional development. Elementary and secondary teachers learned how to implement the Pollinators and The Great Sunflower Project: A Driven to Discover (D2D) Curriculum (Strauss, 2015) through a two-week professional development program which met for six hours per day for ten days. This program consisted of whole group and small group cohort instruction. The whole group instruction included defining citizen science, exploring science in outdoor classrooms, and developing a culture of collaborative science instructors in schools. Scientist lecturers,

K12 mentor teacher lecturers, guest speakers, and panel discussants led the whole group sessions. To form the small cohort groups, teachers chose one of the following four topics based on their personal interests: phenology, pollinators, dragonflies, and birds. One scientist and one mentor teacher facilitated instruction in break-out sessions for each cohort group. The participants were K12 teachers and included first-time attendees and returning attendees. They earned a stipend, received materials for unit implementation, and had the option to receive three graduate credits. During the school year, teachers attended two on-campus follow-up instructional Saturdays and four small group meetings.

The professional development occurred at two different institutions. Teachers met at one university, which will subsequently be called “Academy”, on the first day of the course before traveling to a small private college where instructors and teachers attended classes for a four-day residency week. The college’s arboretum and prairie served as the schoolyard setting for data collection in model POS lessons. After the conclusion of the residency week, teachers returned to class at the Academy two weeks after the residency week for five more days of instruction.

Intervention curriculum. The intervention curriculum, Pollinators and The Great Sunflower Project: A Driven to Discover (D2D) Curriculum (Strauss, 2015) supports teachers to teach and conduct POS investigations in schoolyard settings using citizen science as a context to learn and teach POS. I chose the D2D curriculum because it uses citizen science as a context to introduce the process of science (Strauss, 2015) into the classroom. The process of science (Strauss, 2015) as described in the intervention

curriculum differs from the eight POS (NRC, 2012, [Table 1]) identified in chapter one, in the number of steps and nomenclature. However, they are analogous in their content. The D2D curriculum (Strauss, 2015) presents the process of science as a 5-step cycle with the following steps: 1. making observations and creating ‘I wonder’ statements, 2. writing testable questions, developing hypotheses, 3. planning and testing, 4. analyzing and interpreting, 5. concluding and reporting. The first chapter of the curriculum teaches the process of science (Strauss, 2015) and illustrates it as a cycle (Appendix A). The curriculum includes a student template for completing the process of science [(Strauss, 2015); (Appendix B)]. Chapter two introduces the disciplinary core ideas of pollination, plant and insect anatomy and physiology. In chapter three the lessons describe the citizen science project, the Great Sunflower Project (GSP), and GSP protocols. Teachers engage in an independent investigation, which is the lesson in chapter four, based on their pollination observations and experiences from the lessons in chapters one through three. Other authors support the value of citizen science in education as a tool to increase student scientific observation skills (Hiller & Kistansis, 2012) and authentic inquiry experiences that use the POS (Bombaugh, 2000). Stanisavljević, Pejčić, and Stanisavljević, (2016) found using context-based curriculum (i.e., newspaper articles) to teach pollination concepts was more effective than using traditional lecture methods in eighth grade science classes. In another study, Herndon (2017) found middle school students increased their skills to define problems, design and carry out investigations to solve those problems when learning about pollinators through beekeeping.

As background knowledge for the POS investigation, each cohort group studied

the natural history of the organisms and phenomena specific to their content. The teacher in this study, Mr. Logan, was in the pollinator cohort group. The background science content knowledge for the pollinator cohort included: pollination, identification, and differentiation of honeybees, bumblebees, wasps, and flies, ecosystem services, and instructions and practice on the data collection protocol for the citizen science project, The Great Sunflower Project. Gretchen Thune, lead scientist for GSP, originated the project to understand the loss of native bees specifically in urban settings (FAQ, n.d.). In general, pollinators are in decline and the GSP seeks to learn more about the ecosystem services provided by native bees when they pollinate flowers for food production, particularly in urban settings (FAQ, n.d.). Ecosystem services refer to benefits provided by the natural world to “benefit humans, like food, fuel, timber, fresh water, clean air, and medicine (Thompson et al., 2018). When the GSP began, all teachers planted lemon queen sunflowers and documented insect visitors to those flowers only. Since then, the project expanded to recording pollinators on any flowering plants and then entering the data in a database. Participants practiced reading a scientific journal article, “Fruit Set of Highland Coffee Increases with the Diversity of Pollinating Bees,” (Klein, Steffan-Dwenter, & Tscharntke, 2003) as a model for teaching how to read scientific journals with K12 students. The curriculum includes a complimentary version of the article written for middle or secondary students’ reading level for classroom use.

During the professional development, teachers plan and complete a mini-investigation, which is a short investigation used as a model for participating in and teaching outdoor inquiry investigations. During the residency week, individual teachers

wrote questions and I wonder statements of interest to them based on their observations and experiences of pollination in chapters one through three in the D2D2 curriculum. They then shared these questions with their cohort group. Using the teacher questions and ‘I wonder’ statements, the pollinator cohort group selected one of these questions for their cohort research investigation. Teachers developed multiple hypotheses, or all the possible results, as a strategy to reduce bias and provide a forum for constructing scientific explanations. To practice constructing explanations, teachers explained possible reasons for why or why not each hypothesis might be supported. Once the questions and hypotheses were in place, teachers developed a plan and carried out the plan in smaller groups of two or three to collect data at the end of the residency week. During the second week of the professional development, they collated whole group data, and learned statistical techniques to analyze these data. Teachers determined a way to depict their data with graphs or charts and wrote their results and conclusion in preparation for the whole-class science conference held on the last day of class. Teachers created a large (approximately 24 inches by 48 inches) printed professional conference poster of their pollination cohort group’s investigation for the conference.

Context

The next section describes the setting of the school, the intervention curriculum, the teacher, student, and researcher participants and the methodology.

Setting of the elementary school. The setting, Lakeside Elementary (LE) is a one-level brick building built in 1988 on approximately 38 acres of property in a suburb of a Midwestern metropolitan area. A large lawn flanks both sides of the building and

there is a flower garden in the front. In the back of the school, a playground and natural prairie are visible from the front parking lot. Mr. Logan spearheaded the planting of the two-acre prairie as a school-wide project. To plant native seeds in the prairie, students used a stomping method inspired by the behavior of bison who lived in the area centuries ago. This setting allowed the class to investigate pollinator populations in their schoolyard. Student enrollment in 2018 was 609 students with 80% White, 6% Hispanic/Latino, 6% two or more races, 4% Asian, 3% Black, and 0.2% American Indian (State Department of Education, 2018). The student population consists of 6% English learners, 16% special education students, 18.4% free and reduced lunch recipients, and 1.3% homeless students (State Department of Education, 2018).

LE was designated as a science, technology, engineering, and mathematics (STEM) school five years prior to the study. According to Mr. Logan, in reality, a heightened focus on high stakes testing in reading and math has limited STEM integration. To make time for the schoolyard pollinator investigation, all fourth-grade level teachers at LE developed the pollinator unit ---based on the intervention curriculum ---as a value-added writing project, meaning an innovative way (Saunders & Rudd, 1999) to add STEM content to a writing project thereby bolstering the school's STEM initiative. Though Mr. Logan wrote the unit, the other fourth-grade teachers collaborated on the unit design in the following ways: presenting a unit introduction in a fourth-grade assembly, creating a list of possible testable questions as models of possible questions to support students in choosing a question, and sharing supplies.

Pollination curriculum in practice: Implementation of the intervention curriculum.

So far, I have described the intervention curriculum, Pollinators & The Great Sunflower Project: A Driven to Discover (D2D) Curriculum. I will now describe how Mr. Logan designed the pollinator unit to be implemented the intervention curriculum in his fourth-grade classroom. I studied the fourth-grade students' engagement in the POS while conducting an inquiry investigation, as taught using the intervention curriculum modified for this specific setting and the patterns observed in (a) peer-to-peer interactions, (b) whole class instruction, and (c) written artifacts including science notebooks.

Table 3.1 outlines the daily implementation of the intervention curriculum implemented by Mr. Logan during the pollination unit. He introduced the students to pollination, pollinators, (including honeybees, bumblebees, wasps, and flies), and observations of flowers and pollinators in the schoolyard prairie. After practicing identification of honeybees, bumblebees, wasps, and flies, students wrote questions and 'I wonder' statements about what they wanted to know about the pollinators and flowers in their schoolyard prairie. The class shared out their questions and chose one question to investigate for a whole-class inquiry investigation. After completing the first whole-class investigation, students divided into small groups to choose new questions to investigate in their small groups.

Table 3.1

Overview of pollinator unit

Day	Topic	POS	Curriculum chapter
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1	What is pollination?	Disciplinary core idea	2
		Asking questions and defining problems	1
2	Observing flowers in the prairie	Disciplinary core idea	2
		Asking questions and defining problems	1
3	Pollinator identification	Disciplinary core idea	2
		Asking questions and defining problems	1
4	The Great Sunflower Project	Developing and using models	3
5	The Great Sunflower Project	Asking questions and defining problems	1
6	Choosing and designing a classroom investigation	Asking questions and defining problems	1
		Planning and carrying out investigations	1
7	How will we collect data?	Planning and carrying out investigations	1
8	Collect data for classroom investigation	Planning and carrying out investigations	1
9-	Publishing our classroom scientific	Using mathematics and	1

10	poster	computational thinking	
		Constructing explanations	
		Engaging in argument from evidence	
		Obtaining, evaluating & communicating information	
11-	Student investigations	All	4
15			

Participants

Students. Student participants consisted of 24 fourth-graders with a binary gender distribution of 14 girls and 10 boys. Using this sample of elementary students, I observed how they engaged in the POS in Mr. Logan’s classroom after he completed the professional development on integrating the POS. All student participant names are pseudonyms.

Small groups. I also recorded student small groups to understand peer-to-peer discussion during this unit. The classroom teacher was unfamiliar with students at the beginning of the year when the unit began so the small groups changed during the first two weeks of content instruction. I recorded small groups and analyzed data from those temporary group assignments as in convenience sampling (Onwuegbuzie, & Collins, 2007). Convenience sampling uses a sample of participants who are in the appropriate setting, in this case a classroom, and who are willing to participate in the study. Group A

is one audio-recorded group from the first two weeks and consists of Joy, Lena, Iris, and Tre. Tre had a special education assistant working with him. In the third, and last, week of the unit, the small groups remained consistent and I audio-recorded the same two groups for that week. Each group had four students with mixed reading levels and one person Mr. Logan characterized as a ‘leader’. Group B consisted of two boys, Blong and Nat and two girls, Aisha and Avis. Blong, an English Learner (EL) sometimes missed science class time to attend language classes, and Aisha, a special education (SPED) student, received in-class support from an educational assistant (EA). Group C consisted of one boy and three girls: Mark, Ayana, Sara, and Serena.

Table 3.2

Composition of student groups

Groups	Students	Demographics
A	Joy	Biracial student
	Lena	White student
	Iris	White student
	Tre	SPED with EA support, white student
B	Aisha	SPED with EA support, biracial student
	Avis	White student
	Blong	EL, Hmong student
	Nat	White student
C	Ayana	Biracial student
	Mark	White student

Sara	White student
Serena	White student

Teacher. Mr. Logan, a pseudonym, is a beekeeper and an expert in pollinators and native wildflowers. He was instrumental in planning and planting a native prairie on the school grounds of his school. He completed the intensive D2D professional development program in summer 2017. I chose to follow Mr. Logan during his implementation of the pollinator investigation unit because I had observed him the first time he taught this unit. He had a strong grasp of the POS, and he delivered the pollinator unit with fidelity. After completing the unit the previous year, a small group of his student volunteers presented the whole-class investigation at a local ecology science fair which further demonstrated Mr. Logan's commitment to his students' development as student scientists. In the excerpt below, Mr. Logan describes some of the benefits of the pollinator investigation unit.

...that's what science is about and this (pollinator) unit really benefits them.

So, let's create teaching [that supports] deeper thinking about what they're doing.

And it's not just learning, it's not about learning terms, it's about doing. And then

that brings in the whole idea of being fortunate enough to be able to go outside,

and they are outside as an extension of the classroom, that's another benefit that

this [pollinator] unit (Strauss et al., 2015) has. (Personal communication,

10/9/18)

Mr. Logan is aware of the differences in teaching the POS from a more scripted, structured way of teaching science. He identifies one of the benefits of the POS unit as

sharing control of the learning with students. At the end, he highlights the value of teaching and learning in outdoor settings which is promoted in the intervention curriculum as a way to develop student appreciation for the natural world.

... it's a lot easier when you throw it at them to take it all over and [the teacher] tries to keep them on task when things get frustrating for them and they really aren't getting it...So, it's that [giving students] control... you have to be a teacher [who] is willing to be okay with it. (Personal communication, 10/9/18)

Mr. Logan's experience in learning and teaching POS, commitment to the process of using the POS to investigate student-generated questions, understanding of pollinators and prairies, and use of outdoor classrooms made his classroom an exemplary setting to study the POS with elementary students.

Researcher. I am a white, upper middle-aged woman, who attended K12 school in a rural area in the same Midwestern state as the school in which this study was conducted. Teaching is my second career, and most of my teaching career was as an elementary science specialist in primarily urban elementary schools with a majority of English learners.

I chose to collect data as a researcher rather than as a bystander to increase teacher and student comfort about having an observer in the classroom for three weeks. My biases include ten years of facilitating lessons from the intervention curriculum with in-service teachers including the development of school gardens for inquiry investigations at schools where I taught. The student population and school setting of LE

School contrasted with that of my elementary teaching career. I taught in an urban setting with limited natural spaces and a student population with over 50% English learners, over 90% free and reduced lunch recipients, and science instruction limited to one-third of the school year's total instructional days. The schools did not make adequate yearly progress in reading, math, or science relative to the state high-stakes achievement tests.

Methodology

I sought to understand the POS for elementary students in one fourth-grade science classroom as they conducted an outdoor inquiry investigation in their schoolyard by collecting recordings of their whole group and small group discussions and their written artifacts. This case study was bound by the experiences of Mr. Logan and his fourth-grade students during their pollinator unit (Merriam, 1998).

The experiences of elementary students in whole class and peer-to-peer interactions in science class during the 15 days of the pollinator unit with class periods ranging from 30 - 90 minutes defined the bounds of this case study. The research questions address the primary goals of the study: RQ1: *How do elementary students engage in the POS while conducting an inquiry investigation?* RQ2: *What patterns are observed in science discourse (a) between peers, (b) in whole class instruction and (c) written artifacts including science notebooks during an inquiry investigation?*

This qualitative study examined audio and video transcriptions of whole class discussion and small group discussions during outdoor observations and indoor class periods, written student artifacts, photos of student data collection, and audio transcription of the teacher interview. The study focused on Mr. Logan's implementation

of the POS using the Pollinators and The Great Sunflower Project: A Driven to Discover (D2D) Curriculum (Strauss, 2015).

Table 3.3

Overview of research design

Research Questions	Data Collected	Data Analysis
<i>How do elementary students engage in POS while conducting an inquiry investigation?</i>	Audio and video recordings <ul style="list-style-type: none"> • whole class instruction • small group discussions 	1. Initial coding based on the attributes of whole class, small group, and independent written instructional settings
<i>What POS are observed in (a) peer-to-peer interactions, (b) whole class instruction, and (c) written artifacts including science notebooks during an inquiry investigation?</i>	Photos <ul style="list-style-type: none"> • student science notebooks, • classroom science conference poster • instructional curriculum • students collecting data in the field 	2. Secondary coding based on the POS: planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations in science or claims and evidence, argumentation from evidence or sense-making, and obtaining, evaluating, and communicating information 3. Quantified time spent engaged in each of the science practices according to setting.

Data methods: The pollinator investigation provided opportunities for students to understand the POS in four contexts: 1) learning about a scientist through participation in

a citizen science project, 2) completing a whole-class investigation, and 3) reviewing a previous class's whole-class investigation, and 4) completing small group investigations. Because of my experience as an elementary science teacher, I was interested in how the intervention curriculum supported the use of POS for elementary students. I collected data every day for three weeks during visits to the classroom for all fifteen days of the pollinator investigation unit. Each day, I collected video recordings of whole class instruction and student field observations, completed the Collaboratives for Excellence in Teacher Preparation (CETP) Classroom Observation Protocol (COP) protocol (Appendix C) which I describe later in the 'Observation' section, audio and video recordings of whole class instruction and small group discussions, photos of student science notebooks, classroom science conference poster, instructional curriculum, and students during data collection in the field. After the unit ended, I audio-recorded a semi-structured interview with Mr. Logan, the classroom teacher.

Observations. I observed all science lessons associated with the pollinator unit. Before the pollinator unit began, the researcher spent two science class periods in the classroom. During these visits, the researcher introduced herself and explained the purpose of the study. She answered questions about the research and joined the class in two outdoor lessons where student small groups identified a tree for observation throughout the school year.

Unit implementation. The unit took place in class periods of 30 - 90 minutes for fifteen consecutive days. At each observation, Mr. Logan carried an audio-recorder in his pocket to collect audio-recordings of whole-class instruction. I also set up a video camera

at the side of the classroom in view of the interactive whiteboard to collect video-recordings of whole class instruction. The camera focused on the front of the classroom during indoor lessons to decrease student distraction and allow the researcher to interact with students rather than operate the camera. The method is consistent with time-location sampling (Patton, 2015) by recording all students who were present in the classroom during the whole class instruction. Students met in small groups to choose questions, plan and carry out investigations in the schoolyard, and analyze data for some of the class meeting times. Mr. Logan “carefully” (personal communication, 10/9/18) identified the members of the small groups so each group included students with varied reading levels, a mix of males and females, and at least one student with small group leadership skills. Since Mr. Logan knew the students better before students began the small group investigations, he identified new groups based on knowledge of the students and their reading levels in practice. Mr. Logan’s chose groups consistent with maximum variation sampling by choosing a representative mix of student gender and reading level (Patton, 2015). When students met in small groups, I closely followed two small groups by choosing key informants (Patton, 2015), by looking for groups where students consistently verbalized their thinking to maximize data collection. Overall, these sampling methods were flexible and emergent (Patton, 2015) since there were dependent on student attendance and participation during the time and location of data collection and the teachers’ control of group selection. The researcher used Temi, a speech-to-text transcription service, to generate original transcriptions and then edited all audio and video recordings for accuracy.

Collaboratives for Excellence in Teacher Preparation (CETP) Classroom

Observation Protocol (C.O.P.) As part of a National Science Foundation (NSF) project to improve science, mathematics, and technology instruction in teacher preparation programs, the CETP COP is a tool that documents classroom implementation of standards-based instruction [(Appeldoorn & Lawrenz, 2004) (See Appendix C)]. Daily CETP COP documents describe classroom activities and types of instructional strategies in five-minute increments (Appeldoorn & Lawrenz, 2004). The protocol section, “Classroom Description and Purpose” consists of a codebook for describing these five areas in classroom observations: the type of instruction, student engagement in percentage, cognitive activity level, inquiry practice, and use of argument. After the codebook, there is a table to record data in five-minute increments relative to each of the five areas listed above. In the next section, the researcher writes a narrative summary of the entire lesson followed by a table for outlining a detailed description of the lesson in five-minute increments. The last section has nine “ratings of key indicators” in which researchers use a Likert scale to rate the lesson on current science teaching best practices like inquiry, reasoning, and student engagement (Koomen, Blair, Young-Isebrand, & Oberhauser, 2004). These ratings of key indicators are modifications made to the protocol. I used this tool to document the length of time and the type of instruction used in the classroom.

Interview. Two weeks after the implementation of the unit lessons, I recorded a semi-structured interview with Mr. Logan. The interview questions focused on the process of teaching inquiry and reflections for next steps in inquiry instruction (Appendix

D). The interview responses explain what the process of using schoolyard inquiry investigations was like for Mr. Logan and his grade-level colleagues. It contains questions about choosing the topic of the investigation, students' understanding of the POS, assigning students to small groups, and describing differences between this science unit and other science units Mr. Logan teaches. The interview was audio-recorded and transcribed verbatim.

Artifacts. I photographed student science notebook pages and other written artifacts from the unit like post-it note responses and investigation templates from the days of the investigation to assess individual student's understanding of inquiry in whole and small group work. I looked for evidence of students' frequency and depth of the POS, particularly in their small group inquiry investigations. I photographed the whole group inquiry investigation poster as evidence of the final communication document summarizing the investigation.

Method of Analysis

Using Miles, Huberman, and Saldaña's (2014) deductive qualitative analysis, first I created a codebook based on the practices of science (Strauss, 2015) introduced by the instructor from the D2D2 professional development (Strauss, 2015). As mentioned previously, the steps in the intervention curriculum's process of science are different from the POS (NRC, 2012) but are analogous in content. The steps in the intervention curriculum's (Strauss, 2015) process of science are: 1. making observations and creating 'I wonder' statements, 2. writing testable questions, developing hypotheses, 3. planning and testing, 4. analyzing and interpreting, 5. concluding and reporting (Appendix A).

Simultaneously, I grouped these codes by the three instructional modes: students in peer to peer (ptp) discussion, whole group discussion, and written artifacts. After assigning codes to the data, I grouped the process of science codes [(Strauss, 2015) (Appendix E)] into the POS (NRC, 2012): planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, constructing explanations in science or claims and evidence, argumentation from evidence, and obtaining, evaluating, and communicating information (refer to Table 3.1). In creating this hierarchy, there were more assigned codes in two of the practices than the remaining six codes. Those dominant practices were asking questions and defining problems and planning and carrying out investigations Figure 3.1).

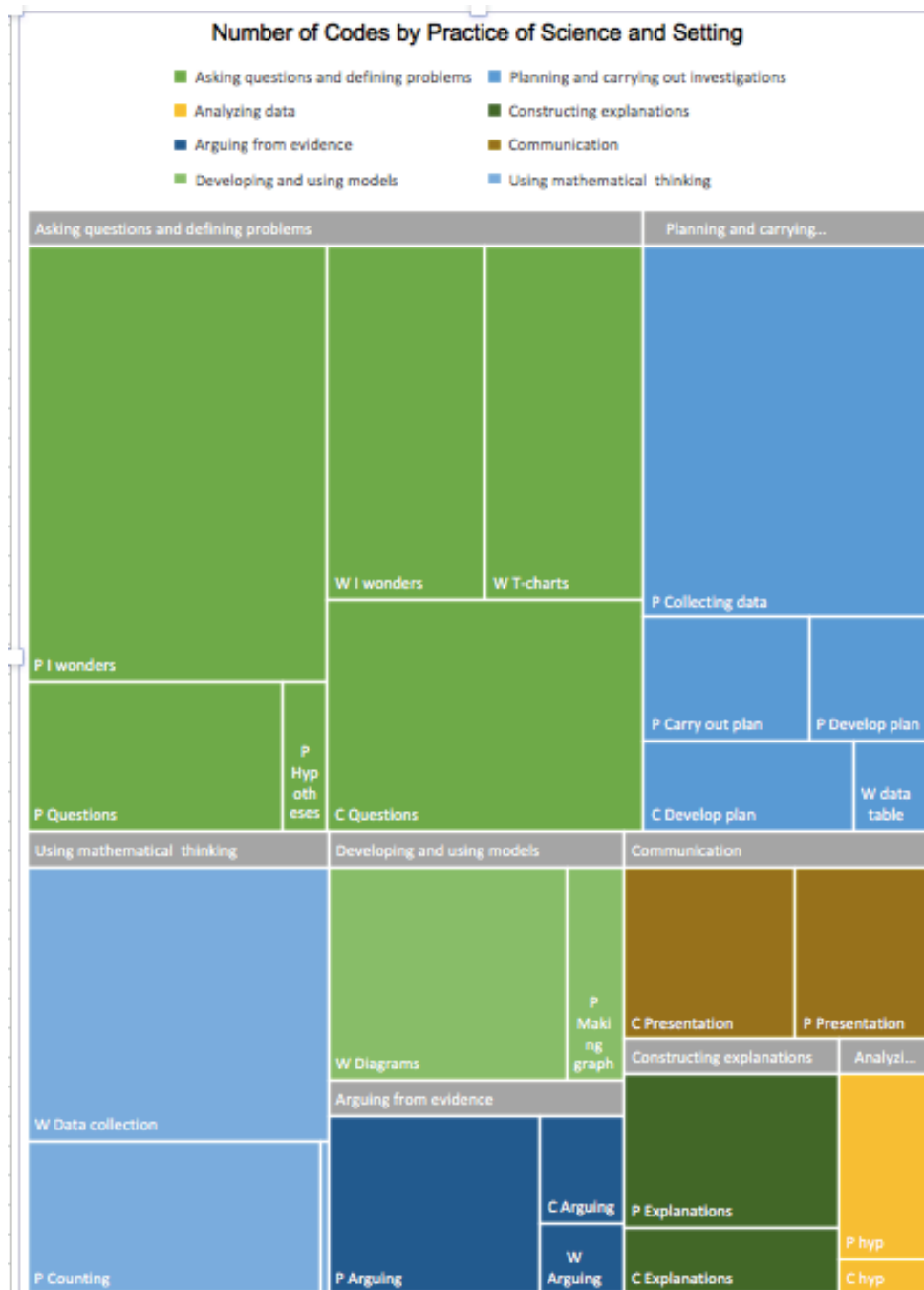


Figure 3.1: Tree map of all codes by practice of science. The whole rectangle is divided into eight sections coinciding with the eight POS, labeled in a banner at the top of each section. Each of the POS sections is further divided into smaller parts signifying coded data. These smaller parts are labeled by code. The first letter of each code signifies the context, P for peer-to-peer interactions, C for whole-class discussion, and W for written

artifacts, and the rest of the code describes the data. Under the category “analyzing data”, both boxes represent hypotheses.

I used open coding to look for broad themes in each piece of data and then re-read them to identify patterns and repetitions. Then I compared across data exemplars to evaluate whether data with the same codes were similar and made the necessary changes. Finally, I looked for broad categories.

In chapter three, I described the conceptual framework and methodology of the case study designed to understand fourth-grade student implementation of the POS (NRC, 2012) using a citizen science curriculum in a pollinator unit. To understand student use of the POS, I analyzed student discussions during whole class instruction and small groups and written artifacts. In the next chapter, I identify claims and cite evidence to support those claims.

Chapter 4

Results

After describing the D2D curriculum and research context in the previous chapter, in this section, I discuss results of the research question: *What practices of science (POS) are observed in (a) peer-to-peer interactions, (b) whole class instruction, and (c) written artifacts in science notebooks during an inquiry investigation?* I describe three themes related to the POS in the fourth-grade classroom during a pollinator unit. The three broad themes are: 1) discussion at the heart of the POS, 2) models of the practices of science as instructional tools and 3) the systemic nature of POS. In this chapter, each of the themes is discussed separately through the lens of the three contexts and eight POS. To support the results, I included excerpts of discussion and written artifacts. Small groups consisted of three groups: Group A, Group B, and Group C. Group A members' pseudonyms were Joy, Lena, Iris, and Tre; Group B members were Nat, Aisha, Avis, and Blong, and Group C members were Mark, Ayana, Sara, and Serena. In whole-class discussion, I referred to other students who were not part of these small groups by "Student #".

Claims

1. Discussion: The heart of science practices. Discussion was a pervasive, integral component of student engagement in the POS. Peer-to-peer discussion occurred between students when they worked in the small groups to complete investigation tasks. Whole-class discussion was teacher-led discussion which occurred after direct instruction as a way for students to practice skills the teacher taught during direct instruction. Figure 4.1 shows the number of times practices of science themes were observed in each of the

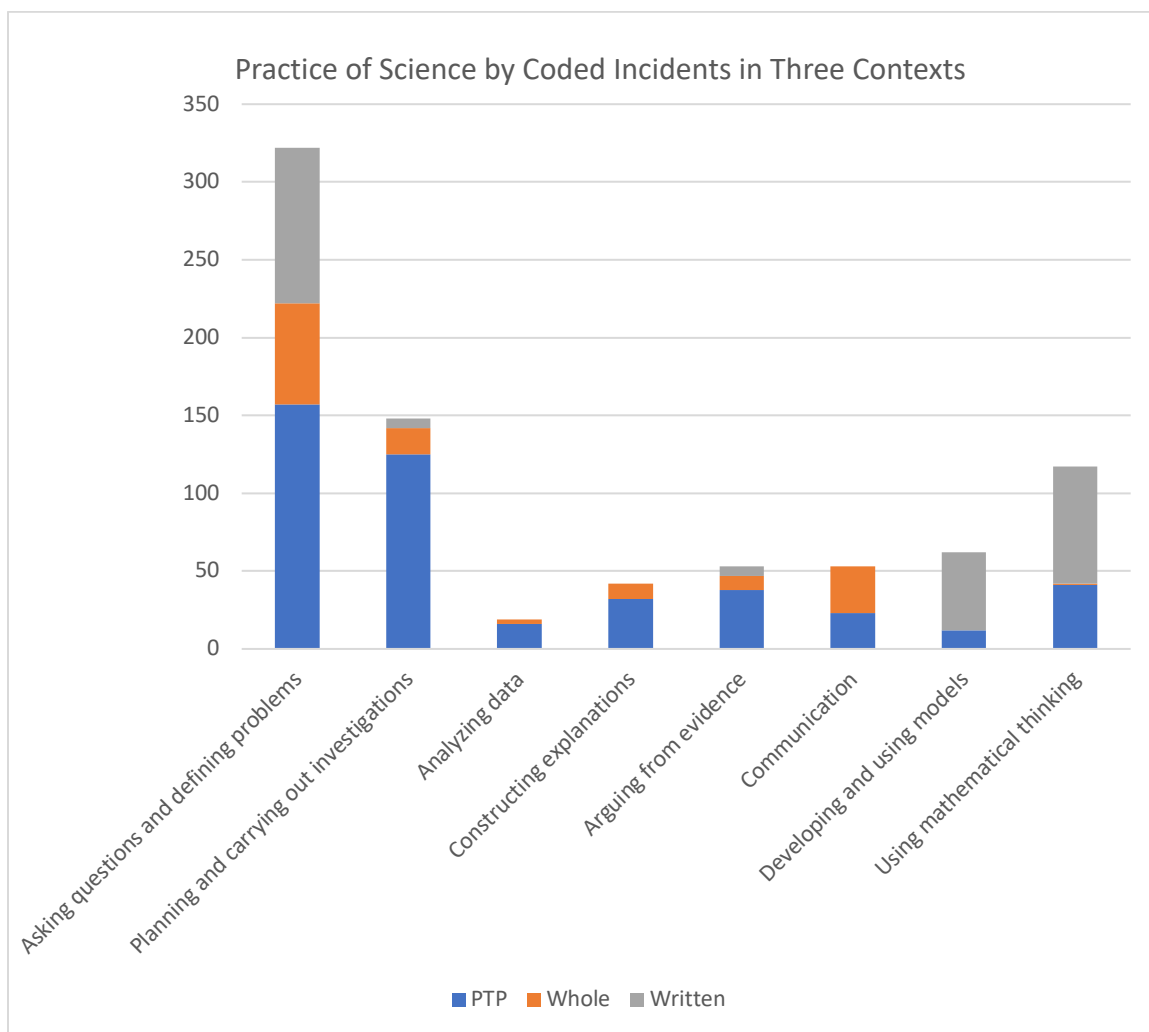


Figure 4.1: Number of codes in content and POS. Each bar represents the number of codes associated with each POS, and each bar is divided proportionally to the number of codes in the three settings: peer-to-peer discussion, whole class discussion, and student writing artifacts.

three research settings: peer-to-peer discussion, whole class discussion, and written artifacts. Overall the predominant context was peer-to-peer discussion with students engaged in the POS asking questions and defining problems. In the next section, I describe and include one example of peer-to-peer interactions for each of the POS.

Practices of Science Observed in the Context of Whole-Class Interaction. In this section, I summarize the POS codes in the whole-class discussions, which often occurred during direct instruction. Mr. Logan used direct instruction to teach pollinator content and describe the POS. In whole-class instruction, discussion was between the teacher and an individual student with other students listening in and sometimes contributing ideas. Overall, this context generated the least number of POS codes that were assigned to capture student voice. In this section, some of the contributing students were not in Groups A, B, or C so instead of using the student pseudonym, and I use the generic term student followed by a number.

The predominant POS observed during whole class interaction was Asking Questions and Defining Problems. Students generated many questions in whole class instruction by writing them on sticky notes for the question board in response to the content instruction. These questions were written and shared verbally in response to content shared in slide presentations, videos, and whole class discussions. This bank of questions provided examples for understanding what kinds of questions lead to investigations as potential testable questions.

On the first day of the unit, the class watched informational videos about pollination and pollinators. During direct instruction, Mr. Logan asked students to write observations and “I wonder” statements in their notebooks. An ‘I wonder’ statement is a question framed in the form of a sentence prompt, “I wonder...” and the student completes the sentence with something they want to know more about. Before students began writing their observations and ‘I wonder’ statements, Mr. Logan invited students to

share examples of ‘I wonder’ statements to the whole class. A sample of students’ ‘I wonder’ statements during whole-class discussion are listed below.

Why are larvae a different color from the bees? (Nat, Group B)

My ‘I wonder’ is how much pollen can they [bees] carry? (Mark, Group C)

I wonder what color the bee station is. (Ayana, Group C)

These questions were typical of the type of questions coded in whole-class discussion. Some of these same ‘I wonder’ statements were questions students discussed as possible investigation questions in peer-to-peer discussion. Though these ‘I wonder’ statements were not turned into testable questions, they were useful as exemplars to help students practice how to turn these types of questions into investigable questions.

Communication. The second largest number of POS in the context of whole-class instruction was *Obtaining, Evaluating, and Communicating Scientific Information*.

Communication codes occurred in whole class discussion when Mr. Logan shared the Google™ slides presentation of their whole class investigation. This was a template for a slide show for students to document each step of their investigation. For example, slide one displayed the question, slide two displayed the hypotheses, and so on through each step of the POS. He prepared the presentation as focused instruction for students to learn how to create a similar slide show for their small group investigations. The example was observed when they were deciding how to word the question: “Are there more pollinators on the prairie or lawn environment?” Students arrived at this question after discussing possible testable questions which Mr. Logan wrote on the board. Then students discussed the questions and voted for the question they were most interested in investigating. After

the class finalized the question, Mr. Logan led students through the process of completing the Google™ slides template. They started with the question slide and students began a discussion on they should use the word, environment, or some other word:

Mr. Logan: Any comments on the question slide?

Sara: I have one, maybe instead of ‘environment’ we should just put ‘area.’

Mr. Logan: Sara wants to know if we should be put area instead of environment.

Nita: I like environment.

Ayana: I like area better because, you know, it's just more simple, and maybe they [the audience] don't know that word.

Mr. Logan: Whenever you write, you've got to consider your audience. Who are we writing this for? Who's going to want to read this? Let's think about that. Then go back to area and environment. Who are we writing this for? What kind of people would want to read this?

Nita: We're presenting it to the Academy.

Mr. Logan: So, you want to present it to, you're thinking, like teenagers?

So, you're thinking if we bring it to the ecology fair, we're writing it for other students...who are science students, right? And scientists that are at the Academy. So, that could be one of our audiences. Then, on the other hand, I want to present this to our own school population...Last year we went around to different classrooms so we have a pretty diverse, that means a really different audience.

Sara: I think that we should use environment because it sounds more scientific.

In this example, students in the whole class context were considering how to develop a presentation for communication to a broader audience than their classroom. Initially, Sara and Ayana (Group C) wanted to use the word “area” instead of “environment” because it was better to keep the language simple, so it was easier for more people to understand. Nita then asserted that the word “environment” was better because the ecology fair audience consisted of older students and scientists, and the word “environment” sounded more scientific. While participating in the discussion, Sara ultimately changed her word choice from ‘area’ to ‘environment,’ stating that it was the ‘more scientific’ choice for the audience.

Planning and carrying out investigations. Instances where students were involved in planning and carrying out investigations in whole-class contexts were observed 17 times. As one example, students counted pollinator population and diversity in the prairie and the lawn to determine pollinator biodiversity in both of these areas. Students had decided they were going to place a one-meter square tool (Figure 4.2), in the prairie and count the pollinators observed within the square meter for ten minutes. When Mr. Logan asked where they should place the square, a student suggested they should put it in the middle of the prairie and not the edge of the prairie. Here was how the discussion proceeded:

Mr. Logan: You could put it on the edge. but if we're trying to experiment with prairie, probably being close to the edge is just kind of like maybe being close to the lawn. Right? ... We really want to make our areas different, right? Because

that's the thing. That's the variable we want to be different. We're not controlling that one, so we want to make them as different as possible. I can go out on the prairie and we can go out and I'm going, all right, I want to find a good spot because I want prairie to win. Is that a good way to do science?

Students, collectively: No.

Mr. Logan: No way. I'm kind of doing my best for prairie... Is that fair?

Students, collectively: No

Mr. Logan: So, you'd want an area that's kind of mixed...Right, then you're not



Figure 4.2. Students using square meter tool in whole-class investigation data collection. Students counted the number of pollinators in one-square-meter of lawn for ten minutes. The one-square meter tools was made of four one-meter lengths of polyvinylchloride (PVC) (one-inch diameter cylinders made of PVC) pipes joined with right-angle elbows to make four ninety-degree corners.

playing favorites. Yeah, you know what? That's what scientists do, and it's being random about it.

This excerpt illustrates an example of Mr. Logan supporting students through random sampling and fair testing in the planning and carrying out the investigation phase. In the whole class discussion, Mr. Logan demonstrated the importance of developing a plan that accurately produces data to answer the investigation question. First, he discussed how when comparing the lawn and the prairie, it was important to sample areas that were distant from each other and consequently different. Then, with the square meter tool in hand, he acted out moving the tool from one habitat to the other asking if he should look for a “good spot”, meaning a spot with a lot of blooming flowers in it. He described these approaches as “not playing favorites” and “being random about it” when planning and carrying out investigations.

Constructing Explanations. Argumentation from evidence and constructing explanations have similar purposes. For this study, I considered constructing explanations as examples in which students used their own explanations or applied the explanation of their teacher (NRC, 2012); whereas evidence of argumentation came examples in which students “use[d] argumentation to listen to, compare, and evaluate competing ideas” (NRC, 2013, p. 62). I assigned codes for argumentation to instances where students defended their explanations with evidence. There were fourteen examples of students constructing explanations in the whole class context, most of which occurred before and after the whole-class investigation when the students and Mr. Logan constructed explanations. On day 7 of the Pollinator unit, students were at the point in their whole-class investigation where they were ready to collect data. Before students went outside to collect their whole-class investigation data, Mr. Logan had students discuss in their small

groups an explanation for each of the multiple working hypotheses. The whole-class question was, “Are there more pollinators in the prairie or the lawn?” and the multiple hypotheses (Figure 4.3) were the null hypothesis (there will be no difference between the

Hypotheses (Predictions)

H_0 : No difference

H_1 : There are more pollinators in the prairie

H_2 : There are more pollinators in the lawn

Our class thought there would be more pollinators in the prairie H_1 because there are more places for pollinators to hide in the prairie.

Figure 4.3. Mr. Logan’s “Hypotheses” slide for whole-class investigation. Mr. Logan developed the whole-class presentation as a model for students’ small group investigation. Before data collection, the students used these hypotheses to construct explanations for reasoning about why each hypothesis might be supported.

number of pollinators in the lawn and the prairie. Hypothesis one (H_1 : there are more pollinators in the prairie), or hypothesis two (H_2 : there are more pollinators in the lawn). After small group discussions, some of the students shared their explanations in a whole-class discussion. In the following excerpt, two students had explanations for hypothesis one, “there are more pollinators in the prairie.”

Jack: Because the prairie has a lot of flowers in it?

Mr. Logan: Okay, so you're thinking maybe that was based on your observation. There's a lot more nectar to be had in the prairie because it has more flowers, right? ... So, I'm wondering why there would be more pollinators

in the prairie. Our classmate gave a good idea because there's more nectar there, Lena?

Lena: I would say there'd be more pollinators in the prairie because there's [more places insects] could like hide, under stuff like tall grass.

This was one example of students constructing explanations in a collaborative environment with classmates thinking aloud and the teacher prompting students' thinking. This excerpt is representative of students constructing predictive explanations which sets a precedent for students to develop the habit of constructing explanations. Additionally, this method reduces scientific bias as they consider how all hypotheses might be supported.

Argumentation from evidence. All nine examples of arguing from evidence appeared when the whole class collaborated on writing the discussion section for the whole class investigation presentation. Their data supported the hypothesis that there were more pollinators in the prairie than in the woods. Mr. Logan prepared a set of questions for students as prompts for writing the discussion section of the presentation (Appendix F). One of the questions was “who would this investigation be helpful for and why?”. In the following example, students provided arguments for people who would benefit from learning the results of the study and how it would help them. After students discussed in small groups, they shared their ideas with the whole class.

Lena (Group A): I think it could help people that have like apple orchards because if you put like a prairie by like the apple orchard after the bees

pollinate the flowers in the prairie, they [the bees] can be like, oh, I see more flowers in there and they'll [the bees] go to the trees.

Mr. Logan: Let me see if I know what you're saying, if I get it. You're saying if you're a farmer or orchard person who wants to have a good orchard, it'd be smart to have a prairie close by? That's funny because that's exactly what we talked about. Student 1, go ahead.

Student 1: So, we know he [the farmer] likes to mow his lawn a lot, and we said that he shouldn't mow so his flowers and the grass could grow longer. And then the bees could help pollinate.

Mr. Logan: ... So, class, think about that, if you're a farmer, and you have a huge field, should you have a lawn around your field or is it better to have a prairie around your field that's going to have to have a lot of pollinators living in it?

Student 2: Prairie.

In this example, students argued that apple orchard owners and farmers relied on pollinators to pollinate their crops and would benefit from planting a prairie near their orchards and fields since the prairie provides habitat for pollinators. Before sharing with the whole group, students were able to engage in peer-to-peer discussion to think and talk through their arguments which provided practice for a greater number of students to engage in argumentation than whole-class discussion setting would. Regarding the argument itself, we see at least two different small groups discussed the value of farmers planting prairies near fields and orchards to attract pollinators to their crops demonstrating student learning and understanding of the value of pollinators for food

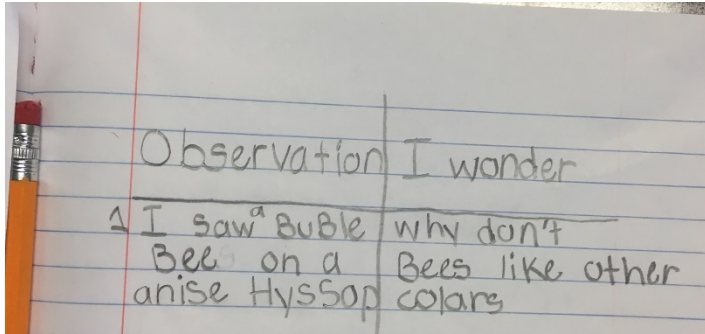
production in the pollinator unit. In other words, students were able to provide applicable evidence from the pollinator unit for the purpose of argumentation. In the next section I discuss the POS, *Analyzing data, developing models, and using mathematical thinking*.

Analyzing data, developing models, and using mathematical thinking. In the whole class discussion context, the three POS - *Analyzing Data*, *Using Mathematical Thinking*, and *Developing Models* - had the least number of incidents associated with them (3, 1, and 0 respectively). Students engaged in data analysis when they reviewed their data to determine which hypothesis was supported in their investigation. Students used math in the whole class context as they collated their results for the whole class investigation. Students created their graphs in small group contexts so there were no modeling codes in the whole class context. Other than these examples, few instances of these three POS were observed in the whole-class context.

Practices of Science Observed in the Context of Peer-to-Peer Interaction.

Asking questions and defining problems. During peer-to-peer interactions, students in their peer groups discussed the Practice of Science, *Asking Questions And Defining Problems*. *Asking Questions And Defining Problems* with 157 examples, was present more often than any other practice and about half of those incidents occurred during the peer-to-peer context in outdoor observations as students learned to identify insects and plants.

After observing pollinators in their schoolyard to practice pollinator identification, students used student-generated written observations and ‘I wonder’ statements (Figure 4.4; Figure 4.5 detailed further in the upcoming “Written Artifact” section) to develop a



Observation	I wonder
I saw a Bumble Bee on a anise Hyssop	why don't Bees like other colors

Figure 4.4. Serena's observation and 'I wonder' statements. Students made a T-table in their science notebooks and wrote an observation and an 'I wonder' statements after observing pollinators in their schoolyard prairie.

testable question for a whole-class investigation. Mr. Logan introduced students to the four question categories for determining good testable questions, which came from the intervention curriculum: 1) Look it up, 2) Not answerable, 3) Testable but not practical, and 4) Testable. By day 5 of the unit, students received direct instruction on pollination, pollinator identification, and plant identification and were ready to look at their questions and 'I wonder' statements. The small group recorded in the following excerpt, Group A, included four students named Joy, Lena, Iris, and Tre who read through their questions and 'I wonder' statements to assign one of the four question types to their questions. Tre had a special education assistant working with him and the assistant acted as his spokesperson in this excerpt.

Lena: So, one of mine is how much pollen can a bee carry? I think, I don't really know, do you think you can look that one up? Well, I think would you have to search a specific bee?

Iris: I think you could look that up or ask an expert.

Lena: Ms. Mary [addressing the researcher], we're wondering how much can a bee carry. Would that be like we'd have to search for a specific bee?

Researcher: Yeah, how would you test that?

Lena: We could search different kinds of bees and look it up.

Researcher: But we want a testable question, something you can do out on your prairie.

Lena: We'd take like the pollen - would you do something where you take the pollen off? I might want to do that one when I'm older cause it would take a long time.

Iris: So, then this one is mine I wonder why wasps have small waists? I think I could look that one up.

Lena: Yeah, I think you could look that one up. Now we need to find one that's testable [addressing other students in the group] Joy, do you think you have one that's testable? Or Tre, do you have one that's testable?

Tre [Special education assistant reading from Tre's writing]: I wonder what kinds of bees are in our prairie.

Lena: Oh, yeah, that's a good one, that's testable.

Iris: Yeah.

Special education assistant: That's what he [Tre] wrote. I wonder why we didn't see any ants? And only one dragonfly was on the flower, why? What kinds of bees are in our prairie?

Lena: I think what bees are in the prairie, if we find out what bees are in our prairie we can probably compare them to, like if we do what kind of bees are in our prairie we could compare it to what kind of bees are not in our prairie.

Joy: Do bees like dark colors?

Iris: That one we could look up.

In this excerpt we see students reading their questions aloud and categorizing each question. Iris's question, why do wasps have small waists, was an example of question that "look it up". An example of a testable but not practical question was Lena's question: How much pollen can they [bees] carry? This question may be testable, but fourth-graders did not have the time, background knowledge, and materials required to investigate this question in the fifteen-day unit. Tre's question, What bees are in our prairie? was an example of a testable question. Students used discussion to consider how they might conduct an investigation to answer their questions or "define problems", helping them to categorize the questions. Lena verbalized her reasoning, and other students indicated they were following along in agreement demonstrating how small group discussion served as a supportive context for learning the new skill, identifying scientific questions. In this example, the POS of developing questions required students to look ahead to the next practice, planning and carrying out investigations. As students began to plan an investigation to answer their question, they needed to consider whether they could address their question within the time, material, and skills constraints of a fourth-grade classroom.

Planning and carrying out investigations. Planning and carrying out investigations accounted for the second highest number of POS incidents with over half cited during the peer-to-peer context. Many instances of planning and carrying out investigations occurred during outdoor observations when students learned to identify

insects and plants and when they collected data for their whole-class and small group investigations and were directly tied to students' efforts at developing testable questions. Planning and carrying out investigations was observed when students met together to develop plans or the procedure they eventually used to carry out the investigations such as in the example which follows.

After Mr. Logan provided direct instruction on necessary pollination content and students completed the whole-class investigation asking the question, are there more pollinators in the prairie or the lawn, Mr. Logan assigned new student groups to develop a new question for a small group investigation. In the following excerpt Group C, consisting of Mark, Ayana, Sara, and Serena, was discussing their plan to answer their small group question: "Are there more pollinators in the prairie or the woods?"

Sara: But, we're going to take a meter square, go in the woods, toss it somewhere.

Ayana: We don't toss it...

Sara: Yes, toss it, cause then it's in a random spot, and then watch it for ten minutes.

Ayana: I don't want to toss something.

Sara: Well, you don't need to then, someone else will.

Mark: I want to.

Sara: We'll watch it for ten minutes, count all for pollinators.

Ayana: What if we throw it really high and it gets stuck in a tree?

Sara: We're not going to do that.

Mark: But there's not a tree on the prairie.

Ayana: But I'm talking about the wooded area.

Mark: Oh, the wooded area. Yeah, we're just going to throw it lightly.

Ayana: But why do it in the soccer field?

Sara: Because everybody's going to be going in the prairie and we already know part of the data for 'in the prairie' [from the whole class investigation] ...

Mark: What is the meter square? ...

Sara: The two-meter squares, this one, [pointing to what she wrote] meters square. [pause as students write] and then you have to check it.

Ayana: What do you mean by check it?...

Sara: Checking all the pollinators You know what I'd do? I'd toss it out; we will toss the square randomly and then where it lands we watch for ten minutes. And then we write down what pollinators we see, and then we go to the prairie and watch it for ten minutes again and see which one [woods or prairie] has more [pollinators].

Group C had little discussion around the substantial points of their investigation plan such as why they were using the meter-square tool or the amount of time they would be observing. This may be because Group C's investigation question was very similar to the whole-class investigation in that both investigations compared the number of pollinators in two distinct habitats on the schoolgrounds. The whole-class counted pollinators within a square meter defined by a tool that marked a square meter for ten minutes, and Group C used the same method to count pollinators. This exchange

demonstrates how students discussed whether they would throw or toss the meter square tool. Ayana indicated concern about throwing the meter square tool as the tool might damage a tree when they counted pollinators in the woods, so they used the word toss in hopes the gentle toss would not damage trees. One area of confusion was when Sara says they will “check on the square meters”. Ayana wondered what check meant for their plan and Sara described it as process of counting pollinators. Students used the peer-to-peer discussion context to iron out procedurally-based areas of confusion which allowed them to develop a plan they could use to carry out their investigation.

Engaging in argument from evidence. Engaging in argument accounted for the third most common POS with 53 instances, mostly occurring in peer-to-peer interaction. In their small-group investigation, Group A, Sara, Serena, Ayana, and Mark, wondered if there were more pollinators in the prairie or the woods. Their results supported the hypothesis that there were more pollinators in the woods. In this example, students initially listed possible explanations with little argument until their teacher encouraged them to defend their ideas.

Sara: I think it was that way [more pollinators in the woods] because they could go on trees because it was a cold day...Because there's a lot of box elder bugs...

Mark: Okay, What's another reason? It's more shady in the woods. ...

Ayana: ...The flowers weren't blossoming that much.

Sara: That's not what we said.

Mark: So, what did you say?

Sara: Alright, somebody else say something.

Ayana: There were a lot of boxelder bugs in the woods...

Mark: Yeah, that supports it.

Sara: Okay what's another one, does anybody else have an idea? Why do you think there was less in the prairie? We already have because it was a cold day? Because there wasn't a lot of flowers?

Serena: Wait, what?

Sara: Because all the flowers were dying.

Mark: Because all the flowers are in the prairie.

Ayana: No, because they were dying.

Mark: The flowers are dying.

Sara: The second one was because it was shady... and there was sap on the trees.

It was windy... Because it was a cold day, because the flowers are dying, it was a shady day...because there's sap in the trees...

Mark: It was windy, right?

Ayana: And hay can protect you and keep you warm.

Mark: Hay? That was grass.

Ayana: I know.

Mark: So, it wasn't hay.

Sara: It was a little more cold than it was windy, so what's another one? Maybe because all the pollen in the flowers is taken by bees, they have no pollen.

Ayana: Nectar you mean?

In making these claims for why there were more pollinators in the woods,

students were not connecting the scientific reasoning behind their explanations about why there were more pollinators in the woods than in the prairie possibly due to their inexperience in using the POS in an authentic investigation. Mr. Logan joined their small group and questioned them about why, from a scientific perspective, cold and shade in the woods would attract more pollinators to the woods than to the prairie. Here is the next section of the discussion.

Sara: Maybe they're attracted to sap in the trees because sap has sugar...

Mr. Logan: You wrote 'cause the flowers have nectar. Are you saying there's more flowers in the woods?

Ayana: No.

Mr. Logan: That doesn't make sense either... were there more green plants in the woods?

Ayana: A lot.

Sara: Maybe there is something on the trees they like to eat.

Ayana: Maybe they have their homes up in there... [Maybe] that's their habitat.

Toward the end of the discussion, students began to respond to Mr. Logan's probing questions to explain their results. Students connected the idea that shade is usually associated with cooler temperatures which is inconsistent with attracting insects so there must be another factor that attracted pollinators to the woods. They considered food sources other than nectar that would be in the woods like sap, leaves, and bark. The small group context allowed students to think aloud and discuss their reasoning about their investigation results.

Constructing explanations and designing solutions. The fourth highest number of POS incidents was constructing explanations. As described earlier, constructing explanations and arguing from evidence have similar purposes. In constructing explanations, the majority of the evidence came during whole-class discussion, but when students constructed explanations in peer-to-peer discussion, they identified which hypothesis was supported and then discussed possible explanations for that finding. In the following Constructing Explanations example, Group B ---consisting of Nat, Aisha, Avis, and Blong--- studied the question: “Are there more bees or ambush bugs on goldenrod?” Their results supported the hypothesis there were more ambush bugs than bees on goldenrod. Nat begins this excerpt by reading Mr. Logan’s directions to the small group.

Nat: Think of as many reasons as you can of why your hypothesis was supported.

Think about differences in weather, location, different flowers, differences in pollinators.

Avis: So why do you think there was more ambush bugs than bees?

Nat: Because it was cold. Because it is was colder. Bees like-

Aisha: He stole my idea. He stole my idea.

Nat: - I think. I think bees like warmer weather, that's why we saw more ambush bugs.

Group B used small group discussion to summarize their explanation for their investigation results. The explanation was discussed with their teacher the previous day while students were conducting the investigation in the field. The POS of constructing explanations mainly occurred in whole-class discussion with significant teacher input. In

peer-to-peer discussion students showed that they understood the background information provided by the teacher about the ways cool temperatures impact insect behavior.

Obtaining, evaluating, and communicating information. Communication represented 53 instances, tied with *Engaging in argument from evidence* at the third most frequent total number of POS, mostly in the context of peer-to-peer interaction. All of these POS occurred in the third week of the unit as students planned, carried out, and analyzed data for the small group investigations using a Google™ slides template provided by Mr. Logan to help them organize each step of their investigations and prepare them for communicating their projects with others. On days 11 to 15, students spent the whole class period in peer-to-peer discussions. They used the teacher-provided Google™ slides template on days 11 and 12 of the unit to complete the question, hypothesis, and plan portions of their presentation. On day 13, students collected data for their small-group investigation, and on days 14 and 15, they added data displayed in a bar graph, data analysis, and conclusions.

In Group C ---Sara, Ayana, Serena, and Mark--- Sara initiated a discussion on how to communicate their findings to the reader to provide the most detail about their work. The investigation compared the number of pollinators in two schoolground habitats and differentiated between the types of pollinators in each habitat for their small group investigation. One pollinator category was “other” to accommodate possible unanticipated pollinators. Sara suggested they break down the specific pollinators in the other category.

Sara: Guys, instead of other, should we just have like flies and, um [ambush]

bugs?

Ayana: No, cause we don't want to write everything down...

Sara: But what if they don't know what we mean by others?... I just don't want to be writing 13 for others if they don't know what we mean by others.

Ayana: Everything else is zero.

Sara is thinking ahead to how a reader might interpret their findings and wants to provide clarity. Sara drops her concern when Ayana disagreed, and the other group members did not engage in the discussion at all. The other students may have wanted to keep the data simple or they may not be familiar enough with this type of audience to realize Sara's point and so the group did not break down the type of insects counted in the "other" category.

Using mathematics and computational thinking. Figure 4.2 showed that mathematical and computational thinking had the fourth fewest incidents --- 50 instances-- associated with them compared to the other POS in all contexts. However, most of the mathematical and computational thinking that was observed occurred during peer-to-peer discussion. Mathematical and computational thinking referred to counting insects during outdoor observations and data collection or when creating tables and graphs to depict their results. In this excerpt, Group C (Sara, Serena, Anaya, and Mark) counted the number of pollinators in the woods and in the prairie to determine which habitat had the most pollinators. As their pollinator count was wrapping up, student discussion revealed their use of mathematics to understand their investigation results. At the beginning of this

excerpt, students had finished counting pollinators in the woods and were about to finish counting pollinators in the prairie when Anaya checked the results.

Anaya: How much did we get for the woods?

Sara and Mark: We had 13 beetles and four others...

Mark: The four others were flies.

Anaya: Okay.

Mark: The prairie might actually lose. [compared to the high number of pollinators in the woods]

Sara: We only had three things [pollinators].

Anaya: I know wasp, grasshopper, and other.

Two minutes later students review their insect observations:

Anaya: Oh, we got one wasp, one grasshopper, and three flies.

Mark: No, two.

Anaya: Oh yeah, just two.

Students continued to observe and then after three more minutes return to the discussion about which habitat had the most pollinators.

Mark: The prairie's going to get beaten.

Anaya: Yeah, I didn't think that. I thought that maybe the woods might win, but I thought the prairie would win from my last time here.

Though there was no direct instruction telling students they would employ mathematics in the pollinators unit, students did use simple mathematics when they counted and compared the number of pollinators for their investigation results. Here we see evidence of the POS *Using Mathematics And Computational Thinking* producing evidence for students to use in the POS, *Analyzing Data, Constructing Explanations, and Engaging In Argument From Evidence*. Before students were asked to summarize their results, students began to discuss with each other in their small groups whether the woods or prairie habitats would “win” demonstrating they understood the meaning of the results. They also used peer-to-peer discussion to clarify with each other how many different types of pollinators they observed.

Developing and using models. Overall the *Developing and Using Models* POS was identified less than other POS with 15 overall, which was not surprising given that it was not an integral part of the intervention curriculum. The main model introduced by Mr. Logan was the model for communicating scientific information using a science presentation poster created from a Google™ slides presentation template. The original model introduced to students was the previous year’s whole-class investigation poster (Appendix G). Mr. Logan provided another model of the poster when he created a poster of the current class’s whole-class investigation (Appendix H). Both of these posters depicted the investigation data in a type of model, a bar graph with multi-colored bars to compare the categories in the investigation. Students made a multi-colored bar graph for their small-group investigation presentation. Modeling occurred in peer-to-peer discussion when small groups created these bar graphs. The students discussed the

mechanics of context up the spreadsheet and the multi-colored bar graph. For most fourth graders, this was the first time they used the Google™ sheets to make a bar graph. In the following example, Group C ---Sara, Ayana, Serena, and Mark--- talked through how to make the bar graph using Google™ sheets on their individual Chromebooks™.

Mark: Do we want a bar graph?

Ayana: Yes.

Mark: Fine. That's not a graph it's a chart...Where's the bar graph?

Sara: Can I help you, Mark?

Mark: There's no bar graph.

Sara: Yes, there is.

Mark: 1, 2, 3, 4, 5, okay, 15, 16, 17 [Mark is counting the tally marks in his data collection sheet that correspond to the number of pollinators, so he can enter the numbers in the spreadsheet to make a bar graph.] I know, I do know how to do this. [make a bar graph] Oh, yeah, I didn't highlight [the table in the spreadsheet] ...So now I hit the, press on this [return key], once I've highlighted it?[confirming how to make a bar graph]

Sara: Uh-huh.

Mark: Is this how it's supposed to be? [showing Sara his bar graph]

Sara: That's how it's supposed to be.

In this example, students discussed how to use the Google™ sheets to make a bar graph and confirmed the teacher's expectations for the bar graph at the same time they created the graph. When making a graph in Google™ sheets, the program generates a pie chart

unless otherwise specified. For students who were new to making graphs in Google™ sheets, they usually made a pie chart first until they learned how to make a bar graph.

Written Artifacts.

Finally, written artifacts was the third context for student evidence of using the POS in a pollinator unit. Students generated eleven written documents during the pollinator unit (Table 4.1). The largest number of documents was created in the *Asking Questions and Defining*

Practice of Science documented	Context	Written artifact	Number of artifacts generated
Asking questions and defining problems	Independent	Observation/I wonder T-charts	2 per student
	Independent	I wonder sticky notes	2 per student
Planning and carrying out investigations	Small group	Data collection sheet	1 per group
Using models	Small group	Labeling flower parts	1 per student
	Small group	Drawing prairie plant	1 per student
Using mathematical thinking	Small group	Tallying data	3 per student
Arguing with evidence	Small group	Analysis of findings	1 per group

Table 4.1 Written artifacts organized by Practice of Science. The table lists the type and number of student-generated artifacts generated in five of eight practices of science during the pollinator unit.

Problems POS in which they created two T-charts. On the left side of the T-chart, students listed observations and on the right side the wrote a corresponding ‘I Wonder’ statements. The other two artifacts created in the *Asking Questions* POS were the ‘I Wonder’ board (Figure 4.7) and sticky notes (Figure 4.8) for In the *Planning and*

Carrying Out Investigations POS, students created one data collection sheet per small group for their small group investigation. When studying the identification and anatomy of a flower, students created two artifacts in the *Using Models* POS. Students labelled the parts of a flower on one document and drew an observed prairie plant for the second document. Students completed three separate observations in which they counted pollinators for a specified time period and completed a tally sheet for each of these observations in planning and carrying out investigations POS. For the *Argumentation* POS, students listed the occupations that would benefit from their small group investigation findings and how those findings would benefit these occupations.

Asking questions and defining problems. *Asking questions and defining problems* was the most common POS in the context of written artifacts. Written artifacts in the POS of asking questions and defining problems, consisted of students' 'I wonder' statements and observations used in the practice of asking questions and defining problems on the first two days of the unit. Students made a T-chart chart each day in their science notebooks (Figure 4.5). They wrote observations in the left column, and 'I wonder'

observation	I wonder
I saw a spider	I wonder what
I saw yellow flower	type of spider
I only saw two purple flowers	I saw?
I saw two pollinators	I wonder what a bees favorite flower is?

Figure 4.5: Mark's observation and 'I wonder' student notebook t-charts. The 'I wonder' board is a place to house student questions and 'I wonder' statements as a baseline for developing original testable science questions.

statements in the right column. Students used the observation statement as the basis for an 'I wonder' statement or question that might be developed into a testable question later in the unit. Then students wrote one or two 'I wonder' statements on sticky notes and placed them on the class 'I wonder' statements bulletin board (Figure 4.6) for a future

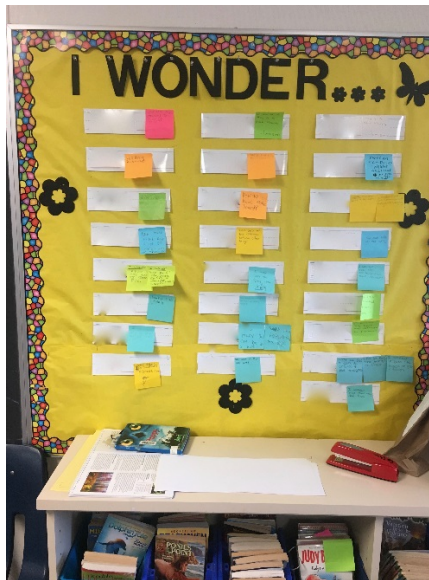


Figure 4.6: Classroom "I wonder" bulletin board. The 'I wonder' board is a place to house student questions and 'I wonder' statements as a baseline for developing original testable science questions.

discussion on identifying a testable question for the whole-class investigation. By rewording or more narrowly defining variables, non-testable questions became testable questions. For example, in Avis's question: "Can bees tell the difference between other things?" Avis needed to more narrowly define what she meant by "other things" (Figure 4.7) to develop this question into a testable question.

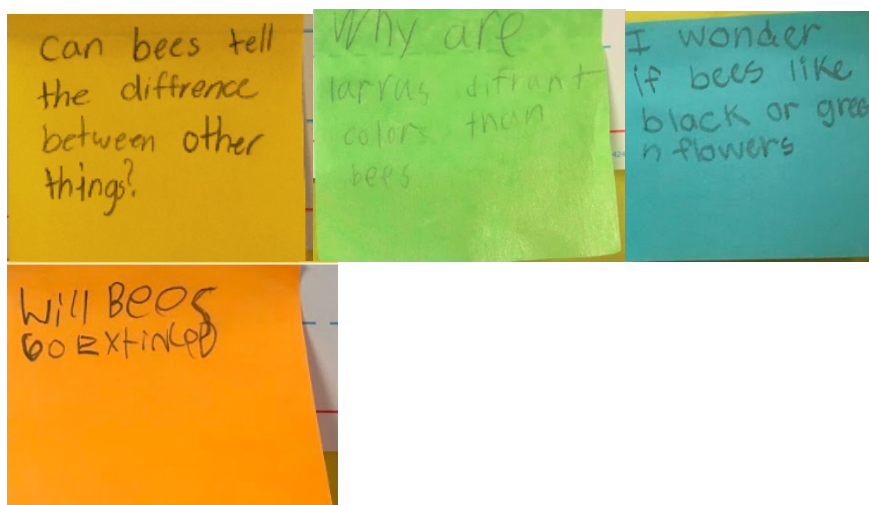


Figure 4.7: Student examples of questions and ‘I wonder’ statements as basis for testable questions.

Using mathematical thinking and computational thinking. The second most commonly cited POS in the context of written artifacts was *Using Mathematical And Computational Thinking*. Students used tally sheets to count pollinators in their science notebooks to collect for three different purposes, collecting data for the citizen science project, The Great Sunflower Project; collecting data for the whole-class investigation; and finally, for their small group investigation (Figure 4.8). Mr. Logan developed the

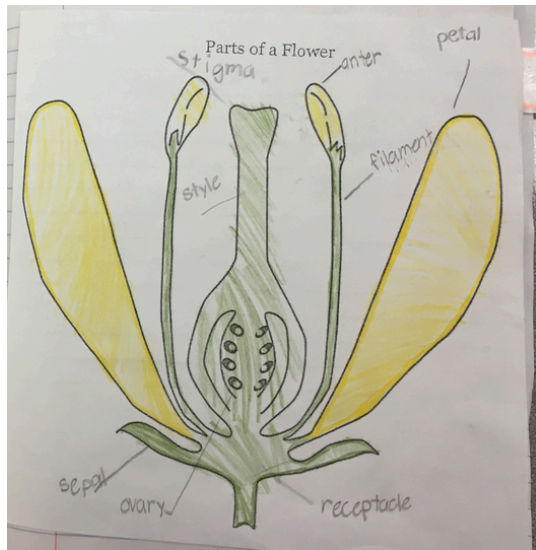
Pollinator Observation Chart				
Honey Bees (look for hair)	Bumble Bees (larger than honey bee)	Wasps Smooth, long abdomen	Flies (look for goggle eyes)	Other (butterflies, ants, beetles)

woods		prairie	
Ants:	Bees:	Ants:	Bees:
Grasshoppers:	Moths:	Grasshoppers:	Moths:
Beetles:	other:	Beetles:	other:
13	4		11
weather:		Soil Temp	
Temp: 53°F cloudy with Time: 11:00 am			

Figure 4.8. Serena's data collection sheets. Student's teacher-generated data collection sheet for the Great Sunflower Project and student-designed data collection sheet for the small group investigations.

data sheets for the GSP and the whole-class investigation and students designed the data collection sheet for their small group investigations.

Developing and using models. The third most common POS in written artifacts was developing and using models and occurred when students studied flowers. On day two of the unit, the teacher introduced the parts of the flower and students labeled a diagram of a flower for the science notebooks. Then students went outside to the prairie with their science notebooks and drew a flower in the prairie along with some other details about their flower. Students labeled the parts of the flower on the diagram and drew their observed prairie flower in their science notebooks (Figure 4.9).



In the space below, draw a picture of your flower.

Name of the flower anise Hyssop Scientific name agastache
pericium

Does it have a scent to attract pollinators? yes

If yes, is it a strong or weak scent? strong

What color is it? purple

How would you describe the shape of the flower? long and
skinny

What plant structures do you see? long and leaves that
are pointy

Would the pollinator need a long tongue or beak to obtain the nectar?
kind of

Figure 4.9. Student labeled diagram and observation sheet. Serena's (Group C) science notebook labeled diagram of flower parts and prairie flower observation sheet. Each student in the class received these two documents for their science notebook on day two of the unit. The direct instruction concentrated on flowers' roles in pollination including the parts of the flower. Students made direct connections with the flowers in their prairie by observing one flower through drawing and description.

Planning and carrying out investigations. The third most common POS used in the context of written artifacts was *Planning and Carrying Out Investigations* followed

by *developing models*. Students documented most of the planning and carrying out of investigations POS in electronic presentations in the context of small groups. As mentioned earlier, in addition to counting pollinators for their small group investigations, students designed one written artifact for planning and carrying out investigations, and that artifact was a data collection sheet.

Arguing from evidence. In written artifacts, each group also generated one written list of occupations they argued would benefit from their whole-class investigation results, there are more pollinators in the prairie than in the lawn. Students created the list while engaging in peer-to-peer discussion to create this written artifact. In the group list in Figure 4.10, students provided an argument for why farmers and beekeepers would

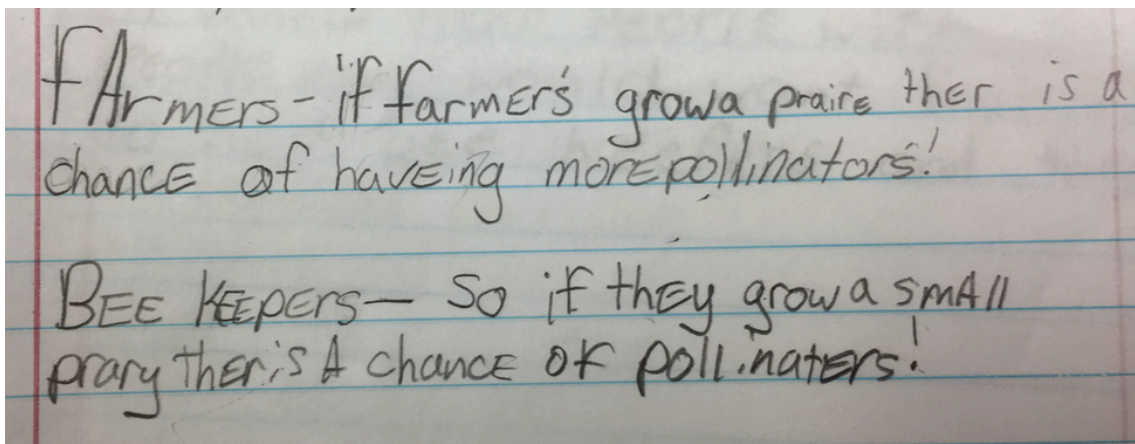


Figure 4.10. Student example of argument from evidence. Student-generated list of occupations benefitting from learning the results that there are more pollinators in the prairie than in the lawn.

benefit from the investigation by planting a prairie to increase the number of pollinators visiting their crops and bee hives.

Communicating results, Analyzing data and Constructing explanations. The remaining three POS were conducted primarily in peer-to-peer interactions. Because

students completed their presentations in the context of peer-to-peer interactions with direct instruction in whole-class discussion, evidence of these POS sits in those contexts. It should be noted here that after the unit ended, each student made their own Google™ slides presentation of the small group investigation as an individual writing project for their writing class.

2. Supporting students toward independent use of the POS through science projects.

A second theme in this study was that Mr. Logan repeatedly used exemplary science projects to gradually develop the POS to prepare fourth-graders to complete a small group investigation using the POS, similar to the Gradual Release of Responsibility (GRR; (Fisher & Frey, 2013) model. In the GRR model, the lowest level of student responsibility is focused instruction in which the teacher shows how to do a task or skill (Figure 4.11). Guided instruction is the second level in student acquiring responsibility,

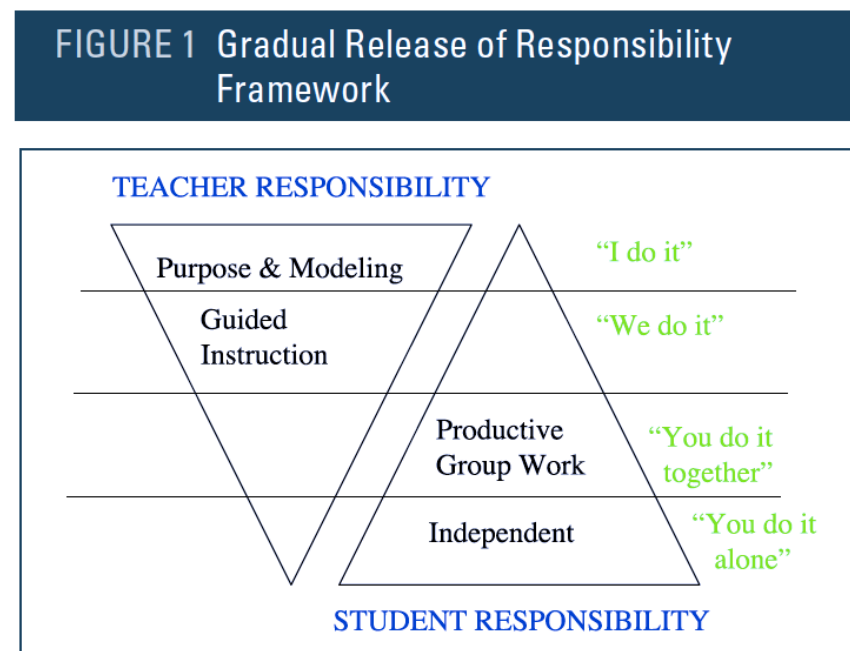


Figure 4.11. Model of Gradual Release of Responsibility, (Fisher & Frey, 2013).

in which the teacher explicitly continues to teach, and the students practice alongside the teacher. At the third level of responsibility, collaborative learning, the students practice the strategy with teacher guidance through direct feedback. At the fourth and highest level, students assume full responsibility to practice independently with teacher feedback. At this highest level, students apply the learned skill to a new situation. The gradual introduction of the POS models supported students to take responsibility for their learning. As fourth-graders, students had limited or no previous experiences planning and carrying out small group investigations with peers. The four POS models were: a citizen science project, the previous year's whole-class investigation poster, a whole-class investigation, and a small group investigation (Figure 4.12). These four examples were



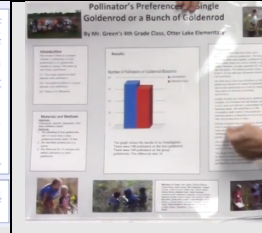
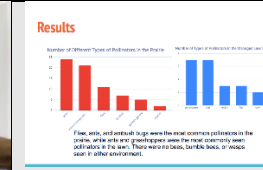
Citizen Science Project	Whole-class Investigation Template and Poster	Previous Class Investigation Poster	Small Group Investigation Template
Focused instruction	Focused instruction	Guided instruction	Guided instruction
	Guided instruction	Collaborative learning	Collaborative learning
			Independence
			
Day 4	Day 6	Day 8	Days 11-15

Figure 4.12: Intervention curriculum POS instructional examples. I used the example of a scientist's citizen science project, the previous year's whole class investigation, and the current class whole class investigation to prepare students to carry out their own investigations. Adapted from Gallagher and Pearson, 1983.

embedded in the intervention curriculum. Mr. Logan used four examples of science projects which allowed him to simultaneously attend to content knowledge and the POS, both of which were integral for students to develop individualized small group investigations at the culmination of the unit.

Citizen science as a focused instruction.

Discussion in whole-class interaction. On the fourth day of the unit during direct instruction on pollination content, Mr. Logan used the citizen science project, the Great Sunflower Project (GSP) as a context for introducing the POS to his students. Since the professional development program Mr. Logan attended used the context of citizen science for POS, he also integrated the GSP into this pollinator unit. During the lesson, students viewed the GSP introductory video in which the project's lead scientist, Gretchen Thune, described the citizen science project. Mr. Logan used direct instruction to introduce GSP and its protocols before students practiced one observation in the schoolyard prairie. The protocol is to observe one flower for ten minutes and write down the number and type of pollinator. GSP served as a focused instruction of highlighting the POS from the perspective of one scientist's investigation. Mr. Logan introduced the model and taught the protocol using direct instruction. After learning the protocol, students divided into pairs and each student pair observed one flower for the presence of pollinators in a ten-minute time period. After completing the protocol, they returned to the classroom and Mr. Logan asked students to share their 'I wonder' statements in a whole-class discussion. Students engaged in the POS *Asking Questions and Defining Problems* by sharing their 'I wonder' statements with the rest of the class. Here is the

discussion that followed:

Lena (Group A): Mr. Logan, I wonder if we'd find an ambush bug like in a different flower besides goldenrod?

Mr. Logan: I wonder. I wonder if it ever could. Yeah, that'd be a good one.

Sara: (Group B) One of my ambush bugs on a different...[inaudible]

Mr. Logan: I'd like to see that one sometime. Interesting. I'll give you a couple more minutes to write down some observations. Maybe your observation is 'I didn't see very many bees.'

After sharing these ideas as a whole class, students wrote these observations in their student notebooks based on their observations as part of the citizen science project which will be discussed in the next section.

Discussion in peer-to-peer interaction. In the following quote from direct instruction, Mr. Logan framed the citizen science project as a model for doing science.

The citizen scientist project does feel different than doing normal schoolwork because we actually get to provide information to the scientist that'll actually provide data that could help figure out why the bee population was declining.

(Classroom observation, 9/13/18)

Mr. Logan's summary served to review the goal of the citizen science project and explicitly pointed out how collecting and reporting data to a scientist's database is different from "normal schoolwork" in which the results are used only for classroom purposes.

During the GSP lesson, students engaged in the POS of planning and carrying out

investigations when they were in the field identifying pollinators and flowers, and then recorded the number and type of pollinator on the flower in a ten-minute time period.

Eben: We're lucky. We have two wasps.

Jack: We're going to keep this one [flower]. Yeah, this is ours.

Mary: [researcher] Yeah. Some little flight flies came in.

Jack: [We will mark the flight flies in the category] Other.

This excerpt is an example of a pair of students who found a flower and watched it for ten minutes to record pollinator visitors. They also used the POS, *Using Mathematical Thinking* when counting and recording their findings.

Written Artifacts. As a follow-through from the whole class discussion, students continued working in the POS asking questions and defining problems as they wrote observations in their student notebooks like those in Figure 4.6. Students were also invited to post them as “I wonder” statements on the “I wonder” board. Additionally, students engaged in the POS of *Using Mathematical Thinking* as they documented the number of pollinators they found during their observation of one flower in the schoolyard prairie.

The GSP citizen science project served as a focused instruction, the lowest level of student responsibility of the POS *Asking and Defining Problems*, *Carrying Out Investigations*, and *Using Mathematical Thinking* as students learned the scientist’s question, the protocol designed to answer the question and observed pollinators on flowers to collect data for the GSP investigation. Mr. Logan did not explicitly name the POS but simply engaged students in using them.

Whole-class investigation Google™ slides used in focused instruction and guided instruction.

On the sixth day of the unit, Mr. Logan introduced the second POS model in the gradual release of responsibility when he demonstrated how to use the Google™ slide investigation template to make their whole-class and small group investigation presentations.

Whole-class interaction. In direct instruction, Mr. Logan displayed the Google™ slides template to students on the screen as he typed in the question and hypotheses:

Mr. Logan: Notice that I have at the bottom of this slide, it says fourth grade Google™ slides template. I'm going to open this up and I'm going to make a copy. I'm going to call this 'Logan pollination investigation.' Okay. This is going to be our official investigation. [Where the template says "title" he keys in "Are there more pollinators in the prairie, lawn or paved environment?"] Is that our title?

Sara: Yeah.

Mr. Logan: Names would be 'Mr. Logan's homeroom,' the date I'm going to put it in later because we're still working on it... 'Hypothesis,' H zero, no difference, right? ... Alright, H one, H one you guys. What's our first guess? What's your guess? What's one of our guesses? Think about it, are there more pollinators in the prairie, on the lawn? What's one of the possible answers? There's more on the...

Lena: Prairie.

Mr. Logan: How many think that's probably going to be our answer? Okay. H two. Umm, Student 3, what would our second one be?

Student 3: Grass?

Mr. Logan: Grass or lawn, right? What would our third one be? There are more on the pavement. Now we're going to talk about how are we going to do this? I'm going to give you three or minutes to think about it. This is like a one, two, three, what are we going to do? We'll write down our tools later.

In this section, Mr. Logan used direct instruction to introduce students to the investigation template and demonstrated how to use it. Then students provided some information on the different possible results to complete the alternate hypotheses as Mr. Logan demonstrated the sentence structure for writing hypotheses in the POS *Asking Questions and Defining Problems*. Once the hypotheses were recorded, he asked students to discuss how they should carry out the plan. After three minutes of discussion, the whole-class discussion continued in guided instruction in the POS *Planning and Carrying Out Investigations* as students suggested a plan for the investigation and Mr. Logan guided them and recorded the plan on the Google™ slides presentation template.

Peer-to-peer interaction. While using the Google™ slides presentation template, students engaged in peer-to-peer interaction briefly to discuss how to plan and carry out the investigation before sharing their ideas with the large group as guided instruction. When Mr. Logan asked students if they remembered what they were going to do for their investigation, Lena volunteered, “We will count how many pollinators are in the woods.” Mr. Logan prompted them to use the word “compare” rather than “count” the number of

pollinators in the prairie and in the lawn. As the discussion progressed, students suggested ideas for carrying out the investigation and Mr. Logan asked clarifying questions like, “Is it practical? Is it answerable? Will we all look at the same goldenrod?” In this way, Mr. Logan provided guided instruction, allowing students to make suggestions about ways to carry out the investigation. Once they developed a plan for carrying out the investigation, as a whole-class they wrote multiple hypotheses. The next day seven of the unit after completing the data collection, students used peer-to-peer discussion in the POS of *Constructing Explanations* to discuss why the hypothesis, there are more pollinators in the prairie, was supported.

Previous fourth-grade investigation poster as focused instruction and guided instruction. On day eight of the unit, Mr. Logan explicitly modeled the POS using focused instruction and guided instruction when he introduced his students to the previous year’s fourth-grade whole class pollinator poster (Appendix G) as a focused instruction of the presentation they eventually made. The unit was half over but students had not been introduced to the poster format of the presentation until day eight. For that reason, Mr. Logan taught the presentation as a focused instruction.

Whole-class interaction. In whole-group discussion on day eight of the Pollinator unit, the previous fourth-grade investigation poster served as a venue for introducing the final format of the poster and represented the POS *Communicating Scientific Findings* to other scientists or peers culminating in a written artifact. Mr. Logan explicitly explained to the students how the poster communicated the POS, specifically asking questions and defining problems.

[Pointing to the corresponding section on the poster] This was our hypothesis.

Here's our introduction. It says, well here, remember we talked about a good title.

What do you think about this one? It says, “Pollinators Preferences: A single goldenrod or a bunch of goldenrod.” That was our title and then it was my class introduction. Introduction, we wonder if there is a greater number of pollinators on lone goldenrod, goldenrod by itself, one little plant, or a group of goldenrod.

(Mr. Logan, 9/19/18)

Mr. Logan engaged students in a whole-class discussion on how to use multiple hypotheses in the POS of defining problems as part of asking questions. The intervention curriculum uses the terminology of null hypothesis and denotes it as H_0 in written documents. Mr. Logan uses the notation “zero hypothesis” as synonymous with the “null hypothesis” as seen in the next example.

Mr. Logan: The question was do more come to single goldenrods or group goldenrods. So, what would be one hypothesis? I like to see those hands up. Iris?

Iris: Um, the first one would be ‘less would come to the lone goldenrod.’

Mr. Logan: Okay. Well how about instead of saying ‘less,’ we want to be positive and say ‘more’ so ‘more come to the lone goldenrod,’ that’d be one. What would be the second one?

Nat (Group B): Less come to the...

Mr. Logan: We don’t say the word less, we use the same word every time. So, Iris said more come to the lone goldenrod, what would be the opposite of that? I’ve got a lone goldenrod and I’ve got a big group of goldenrod. What’s the opposite?

More come to the...

Student 4: bunch of goldenrod

Mr. Logan: ...bunch, and then what's the null hypothesis? the zero hypothesis.

Joy?

Joy: the same.

Mr. Logan: Both [lone goldenrod and bunch of goldenrods are] the same and that's what we did. (Classroom observation, 9/19/18)

In this example, Mr. Logan led students through the steps used to develop multiple hypotheses and used guided practice by asking students to suggest wording of the hypotheses and then using focused instruction as when he told students to use the word "more" rather than "less" to phrase the hypotheses. Mr. Logan proceeds to use focused instruction when he tells students to use the same wording for all the hypotheses and only change the variable.

Peer-to-peer interaction. Students did not engage in peer-to-peer discussion as part of the focused instruction of the poster presentation.

Written artifacts. Students did not produce a written artifact for this model of science. They did observe the previous class's poster presentation which was a written artifact and a focused instruction for the presentation the fourth-grade students produced later in their pollinator unit. The presentation is an embodiment of the communication POS with other POS embedded in the content of the poster. Each section of the poster represented specific POS: questions and hypotheses represented asking questions and defining problems, the plan represented planning and carrying out investigations, the data and graph represented analyzing data, and the discussion represented constructing explanations. The written artifact in this aspect of the previous grade's presentation was a

focused instruction.

Small group investigation as shared and collaborative learning.

One goal of the intervention curriculum in the pollinator unit was to engage students in authentic science experiences and provide opportunities to enact the POS. For the theme, using examples to develop independence in the POS, the small group investigation is the culminating experience, moving students toward taking responsibility for their own investigation. The citizen science project and whole-class investigation were intended to gradually develop students' capacity to engage independently in the practices of science. In the next section I describe how students completed a small group investigation in the three research question settings of whole-class, peer-to-peer, and written artifacts.

Whole-class discussion. For the small group investigation, most of the work was done in small groups. Whole-class instruction consisted of giving directions at the beginning of the lesson and reminding students of their goals for the day. Mr. Logan checked in with the small groups throughout the six days of the small group investigation. At times when an issue came to his attention, he made an announcement to the whole class to share information relevant to all small groups. Sometimes he reminded students of the work that needed to be completed by the end of the day or an announcement about presentation style conventions such as font type. One example occurred when Mr. Logan intervened with Group B that chose a question, are there more bees or wasps in the prairie, he asserted would yield no data in late September.

Mr. Logan: This group, [Group B] I made them choose another question. Do you

know why? They wanted to know if there's more bees or wasps on goldenrod.

Why do you think I had them do a different question?

Annie: It's too cold outside.

Mr. Logan: Because we're not seeing any, so they wouldn't have any data, and that's not going to be any good for doing an investigation, they would have no data. So, I'm going to have them look at other things.

This excerpt exemplifies the small-group investigations as shared and collaborative learning spaces because it shows how Mr. Logan encouraged students to develop their own questions but when one small group needed intervention, he would share that example with the whole class so all students could benefit from the instruction. Overall, students worked independently but, in this example, Mr. Logan made the decision that Group B needed to choose a different question. Students were responsible for choosing the question, but final approval was reserved for the teacher making this an example of collaborative learning between the students' ideas and the teacher's instruction.

Peer-to-peer interaction. Small groups chose their questions independently based on their interests by reading their 'I wonder' statements with input from adults. For example, on the ninth day of the unit, students launched the small group investigation, reviewing their 'I wonder' statements and a document of teacher-generated 'I wonder' statements [Appendix I] to choose a testable question. As Group B read through their 'I wonder' statements, the researcher influenced their analysis of whether a question was testable or feasible in their classroom context.

Nat: I think mine would be testable, why[are] the larva of the bees different

colors from adult?

Researcher: How would you test that? How would you test this [why bees change color in different life stages]? How all the larvae are different [from the adult bees]?

Nat: You can put a camera in the beehive and watch them grow and maybe they'll develop their colors as they get older.

Researcher: Does that tell you why? Can you change your question a little bit? Do you think you'll have time to observe all of them? Is this something you can do in one or two class periods?... How long does it take to go from the larva to an adult? Probably a couple of weeks and at this time of year they're not doing that [change from larva to adult]. Do you think you can to that one [question]?

Nolan: Well, it's a good question.

This example shows collaborative learning in which Nat practices determining testable or “good” questions. Then the researcher used direct feedback to steer Nat away from an investigation on the question about the color of bees at different stages of their life cycle. In contrast, Group C on the same day worked independently to select their investigable question.

Ayana: Why do bees only have stripes instead of other patterns. Also, I said [asked] if humans can eat pollen. That's what I wonder.

Sara: That's [can humans eat pollen?] not really testable because what if it has a chemical we can't have [eat].

Ayana: The other one [question] is that I wonder what color they [pollinators] like best.

Sara: Like here's one, do pollinators like going into the wooded area more or the prairie? Not in the prairie, or you know like that part where the grass is down, that's what I meant by prairie should we do that one? ... so, not in the prairie that part by Ms. X's [classroom] where all that grass is down.

Mark: You mean the stuff behind the soccer field?

Sara: Yeah, do pollinators like that area better or the wooded area?

Mark: Or we could do that area and the prairie.

Sara: Well, we kinda know the prairie.

Sara monitored the discussion, asserted that it would be unsafe to test Ayana's question whether humans could eat pollen. She went on to suggest a question that followed the format of the whole-class discussion since in both questions compare the number of pollinators in two habitats. Eventually, this is the question Group C investigated. They exhibited independence within the safe bounds of choosing a question after the model of the whole-class discussion.

Written artifacts. In written artifacts, students generated two documents of coding. First, they generated a data collection sheet (Figure 4.13) for their small group investigation in the *Planning and Carrying Out Investigations*. Students successfully designed data collection tools for their investigations. This was an area where students succeeded at the independent level with Mr. Logan approving them before printing them. Then, students used that document while collecting data for their small group

investigation used while engaging in the using mathematical thinking POS. Students implemented the data collection sheets at the independent level though during small group data collection, Mr. Logan moved from group to group confirming accurate implementation of the plans.

Together the four models represented opportunities to prepare students to conduct small group investigations gradually while engaged in peer-to-peer interactions, whole-group discussion, and creating written artifacts. Students progressed from focused instructions through guided instruction to collaborative learning to completing small group investigations to enact the POS. In supporting students in the implementation of a small group investigation, asking questions and defining problems was the most commonly cited POS.

3. Overlap of the practices of science.

Mr. Logan's fourth grade class spent fifteen class periods ranging from 30 – 90 minutes in length. The CEPT-COP data provided a breakdown of time spent on each instructional activity including lecture, video, whole-class discussion, outdoor observations, small group discussions, and individual writing time. Looking at the data from the lens of the POS, the instructional activities encompassed multiple POS simultaneously precluding a breakdown of time spent on each POS. In Figure 4.13, a

You're right. So writers, so they know actually what to write about. Yeah.

And then they can also, [inaudible] not scientists. Cause we are the scientists.

Scientists want to know this cause, those are the people who want to know about this.

Or what about college professors?

the people who actually work as a job for pollinators.

A beekeeper?

Yeah, a beekeeper, orchard owners as we said. I think we have



Figure 4.13: Transcribed small-group discussion with coding stripes on the right. This sample of small group discussion shows the overlap of POS codes. The purple line, SCOMP is the code for *Obtaining, Evaluating, And Communicating Results*. The blue line with the code SCERP, represents the student practice of *Arguing From Evidence* POS, The orange line with the code SPCP represents the student practice of *Constructing Explanations*. The overlap between POS is visible in this example of transcribed student small-group discussion with the overlapping coding stripes. In the dialogue, double spaces divide comments from the different speakers. Names were removed to maintain confidentiality.

sample of transcribed small-group discussion shows the overlap of three POS represented by three different-colored coding stripes.

In another example, students engaged in the POS, they focused primarily on one POS, *Asking Questions And Defining Problems*, but responsively reflected on how the question related to the plan (*Planning And Carrying Out Investigations* POS) or the mathematical analysis (*Using Mathematical And Computational Thinking*). The POS emerged as a tightly connected system. Examples of the overlap between the POS occurred in the three research question contexts under investigation, whole-class

discussion, peer-to-peer interaction, and written artifacts. In the next section I describe examples from the whole-class discussion context.

Whole-class discussion. For the pollinator unit, whole-class discussion occurred during direction instruction in response to lectures, video, or responses to outdoor observations. The context of whole-class discussion provided a space for students to share their ideas with responsive instruction from Mr. Logan. As the teacher and students thought aloud together, they worked through their applications of the practice of science and learned from the ideas of the collective group.

Asking questions and defining problems and planning and carrying out investigations inform and influence each other in an iterative relationship. Students used content instruction and observations from preliminary data collection to develop testable for an investigation by writing questions and I wonders. In the following example, as students worked in whole-class discussion to choose a question that was testable, they engaged in the *Planning And Carrying Out Investigations* POS to inform them whether their question was testable and reasonable based on classroom constraints. Student 2's I wonder was whether humans can eat pollen, and then the class considered whether this was a testable question.

Mr. Logan [reading a student I wonder]: I wonder if we [humans] can eat pollen.

Sara: Well, kind of not.

Nat: With a test subject?

Mr. Logan: Who asked this question?

Nat: Student 2

Mr. Logan: Student 2, did you mean will it hurt you or is it good for you to eat pollen?

Student 2: Is it good for you to eat pollen?

Mr. Logan: Yeah, or is it something you could test, or somebody could look up?

Student 2: Test.

Mr. Logan: Tell me why you couldn't look it up to find out?... Could you ask an expert about? Pollen? What would you, how would you test it though? So, you could test it, have one person, a volunteer eat pollen... is that a very safe, real reasonable experiment though? No, it's not safe; I would not let that happen in my classroom to eat something that we don't know is safe [to eat].

Scientists and students engage in the planning and carrying out an investigation POS to determine whether a question is testable or not. In the previous example, Student 2 wondered about humans eating pollen, Mr. Logan defined the problem (*Asking Questions And Defining Problems* POS) by asking Student 2 what she wanted to know, would pollen hurt humans or was it good for humans? When Student 2 said she wanted to know if pollen was healthy for humans to eat, he asked if it was something you could look up or ask an expert. Student 2 proceeded to think about how she would design the investigation (*Planning And Carrying Out Investigations* POS) and said it could be tested. Mr. Logan replied that it was unsafe to give it to students if he didn't know how it would affect them and that he would do anything unsafe in the classroom.

Peer-to-peer interactions. *Students used mathematical thinking when analyzing the data and constructing explanations in peer-to-peer interactions.* In whole-class

instruction, Mr. Logan used prompts to help students use their data (*Using Mathematical And Computational Thinking* POS) to analyze the data (*Analyzing Data And Interpreting Data* POS) and construct explanations (*Constructing Explanations* POS) for their small group investigations. The next example follows Group B in peer-to-peer interaction as students explained why there were more ambush bugs than bees on goldenrod in their small group investigation.

Mr. Logan: Think of as many reasons as you can of why your hypothesis was supported. Think about differences in weather, location, different flowers, differences in pollinators.

Avis: So why do you think there was more ambush bugs than bees?

Nat: Because it was cold. Because it was much colder, bees like...

Aisha: He stole my idea. He stole my idea.

Nat: I think, I think bees like warmer weather, that's why we saw more ambush bugs.

Though students needed and relied on the mathematical fact that there were zero bees and nineteen ambush bugs, the mathematics of counting and comparing which number was greater were mathematical tasks that fourth-graders could understand without making calculations. The next step for students was to construct an explanation for why there were no bees. Mr. Logan prompted them to think about “weather, location, different flowers, differences in pollinators”. During data collection, the teacher told students that bees do not like cold weather and didn’t move much when it was cold. Nate

develops an explanation that there were no bees because it was cold and bees like warmer weather.

In the next example one small group that investigated whether there would be more pollinators on the edge or the middle of the prairie. They argued that because it was a windy day, there were fewer pollinators in the middle of the prairie than on the edge. Mr. Logan helped them think about whether the wind would affect the edge or middle of the prairie more.

Student 5: Because if it wasn't as windy, there would have been a little bit more [pollinators].

Mr. Logan: I wonder if its windier in the edge or the middle. Where do you think?

Student 5: Probably in the middle.

Mr. Logan: Why? Do you guys agree with that? Where would it be windier, in the middle, or on the edge?

Student 6: On the edge.

Mr. Logan: She said middle or no difference. What do you think? Is it windier in the middle?

Joy: I think it's no difference.

Mr. Logan: Have you ever laid down in the tall grass before and it's a little bit windy? Well, if you lay down in the long grass and it's a little bit windy do you feel it more laying down or standing up?

Student 5: Standing up

Mr. Logan: Why do you feel less laying down?

Student 5: If you on the ground you're by the tall grass.

Mr. Logan: So, this is a piece of grass, and I'm wind, and I blow all the way here, it's going to be blocked where? You'd feel the wind up here, but right there, there's a bunch of grass here, does wind go through grass? a little bit? Don't you think it blocks some of it? If I want to get out of the wind, I'd go down. So where do you think there is more wind? Where the grass isn't stopping it? So, I wasn't sure what you meant by wind, so I was asking you.

Student 5: We thought there we were just going to see a couple [of pollinators].

In this exchange, we see evidence of students *Analyzing And Interpreting Data* and *Constructing Explanations* at the same time when Student 4 makes a connection between the presence of “fewer” insects in the presence of wind. She doesn’t *Argue[ing] from Evidence* but when the teacher asks where it would be windier she says, “probably the middle”. Students grappled with developing an argument to defend their conclusions since they had not considered the impact of plants as a windbreak. They needed help understanding the effects of wind as they go back to think about their initial question and predictions and how their results relate to scientific understandings about the effects of plants on wind strength. Students would have benefitted from reading about wind and windbreaks though that is beyond the scope of the pollinator unit. This example illustrates the limitations of elementary students’ experience to engage in the practice of argumentation.

Written artifacts. For this context, the student artifacts consisted of handwritten sticky notes, written homework, and science notebook pages. Most of the written artifacts were generated during peer-to-peer interaction.

Planning and carrying out investigations overlapping POS with using mathematical and computational thinking POS and analyzing and interpreting data POS. Students created their own data collection sheets for their small group investigations. Figure 4.14 shows the data collection sheet for Group A on the left

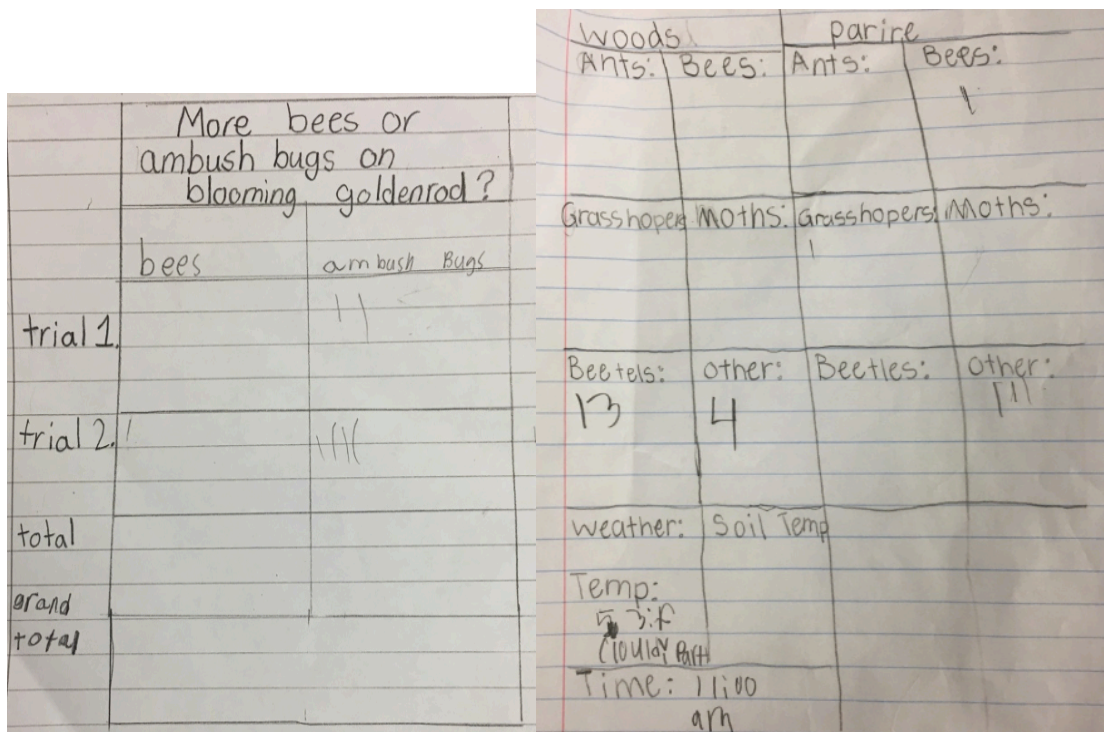


Figure 4.14. Small group data collection sheets. Group A developed a data collection sheet, on the left, for two trials observing blooming goldenrods for bees and ambush bugs in the school prairie. Group B developed the data collection sheet on the right for one trial in woods and one trial in the prairie surveying pollinators in a square meter.

used to count the number of bees and ambush bugs on blooming goldenrod and for Group B on the right used to count the number of pollinators in two different habitats, woods and prairie. In order to develop these meaningful, relevant data collection tools, students

created the tool for use in the planning and carrying out investigations POS while using mathematical thinking to consider a useful format (mathematical thinking POS) and decide the relevant data to collect.

Analyzing data POS, arguing from evidence POS, and obtaining, evaluating, and communicating results POS overlap. As a model, the whole class reviewed the previous year's whole-class investigation poster, are there more pollinators on lone goldenrod or groups of goldenrod. After observing each context of goldenrod for ten minutes, the whole class compiled their and found there were 188 pollinators on lone goldenrod plants and 169 pollinators on groups of goldenrod plants. To practice their data analysis skills, students met in small groups to analyze the results and make recommendations about the relevance of the investigation results. Uzair, Mark, and Ayana wrote two recommendations (Figure 4.15) based on the data, that people who

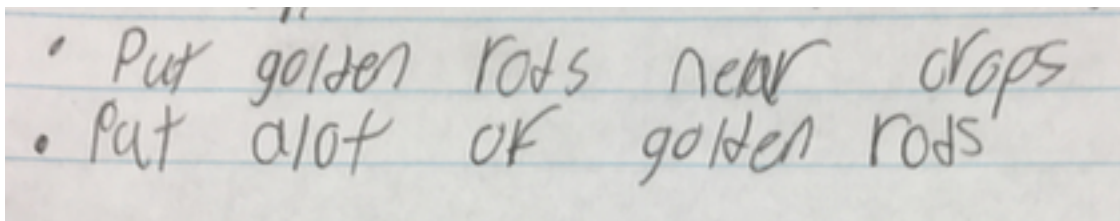


Figure 4.15. Written artifact showing overlap of POS. In the above artifact one small group made the above recommendations based on their data analysis of the whole-class investigation.

grew crops should plant goldenrod near their crops and they should plant a lot of goldenrod. To create the artifact, students interpreted and analyzed data from other investigators (*Analyzing And Interpreting Data POS*), communicated their ideas based on a scientific report (*Obtaining, Evaluating, And Communicating Results POS*), and supporting an argument (*Arguing From Evidence POS*), that farmers plant a lot of

goldenrod near their crops. This example demonstrates how the POS overlap and support each other to communicate scientific information.

In this chapter, I identified three themes, 1) discussion is at the heart of POS, 2) gradual release of responsibility to teach POS, and 3) POS as an overlapping network of practice. There was evidence of these themes in numerous examples of students engaged in whole-class discussion, peer-to-peer interactions, and written artifacts and engagement in all eight POS with asking the questions and defining problems POS cited most often. In the next chapter, I will discuss the importance and implications of these findings for elementary students and their teachers in using the POS.

Chapter 5

Conclusion and Implications

This chapter examines the findings of this study and their relevance for using the POS in elementary science education, and their connections to the research literature. This chapter concludes with possible directions for future research. One finding of the study suggested that direct instruction in whole-class discussion supports students when using the POS in multiple iterations of scientific investigations. A second finding suggested that peer-to-peer discussion promoted student engagement in scientific discourse. A third showed student engagement in the practices of *Asking authentic Questions And Defining Problems* and *Planning And Carrying Out Investigations in familiar settings* facilitated their introduction into scientific dispositions and habits of mind in all three settings. These findings are relevant for elementary science teachers, science educators, science education researchers, curriculum writers, and administrators in improving students' skills and content knowledge in science.

Research Questions

Research Question 1: How do elementary students engage in the practices of science while conducting an inquiry investigation in these settings (a) whole-class interactions, (b) peer-to-peer interactions, and (c) written artifacts in science notebooks and posters?

Research Question 2: What practices of science are observed in (a) whole-class interactions, (b) peer-to-peer interactions, and (c) written artifacts in science notebooks and posters during an inquiry investigation?

When reviewing the findings from research question one, these overall themes emerged: 1) Whole-class discussion of four pollinator investigations across the continuum of inquiry allowed elementary students to engage in the POS; 2) Peer-to-peer discussion promoted student engagement in scientific discourse; 3) Student engagement in the practices of *Asking authentic Questions And Defining Problems* and *Planning And Carrying Out Investigations in familiar settings* facilitated their introduction into scientific dispositions and habits of mind in all three settings.

RQ 1: How do elementary students engage in the practices of science while conducting an inquiry investigation (a) whole-class interactions, (b) peer-to-peer interactions, and (c) written artifacts in science notebooks and posters?

The discussion provided opportunities for elementary students to use the POS during whole-class and small-group outdoor inquiry investigations. There were more incidences of engagement of the POS cited in peer-to-peer discussion compared to the other settings, whole-group discussion and written artifacts in this study, all three settings contributed to engagement in the POS.

Claim 1: Whole-class discussion supports students in inquiry instruction by using multiple examples of scientific inquiry investigations. The teacher used direct instruction through whole-class discussion to introduce content to students and to provide multiple opportunities to practice applying the POS at different levels across the inquiry continuum in the context of life science contents. In the following section, I briefly discuss each of the four inquiry investigation examples.

Example 1. Mr. Logan began by teaching students to identify and write a testable question using student-generated questions based on their field observations and ‘I wonder’ statements. To prompt students to start writing observations he asked student volunteers to share some examples of their ‘I wonder’ statements with the whole class.

In their first exposure to a scientific investigation in this unit through the citizen science project, The Great Sunflower Project (GSP), Mr. Logan led the whole class through the process of sharing ‘I wonder statements’ after collecting data for the GSP protocol. Lena (Group A) demonstrated her ability to generate a testable hypothesis, “Mr. Logan, I wonder if we'd find an ambush bug like in a different flower besides goldenrod?” After confirming the relevance of her idea, Mr. Logan encouraged the class to continue writing their observations and modeled an example, “Maybe your observation is, I didn't see very many bees.” By the close of this lesson, all students had successfully generated at least two ‘I wonder’ statements.

Example 2: On the sixth day of the unit, Mr. Logan used the second investigation example, the Google™ slide investigation template as a communication tool for the whole-class investigation question, Are there more pollinators in the prairie or the managed lawn? As Mr. Logan modeled how to use the template and keyed in the multiple hypotheses (*Obtaining, Evaluating, And Communicating Results*), he also reviewed students’ understanding of writing multiple hypotheses. Specifically, he asked them to provide the hypothesis alternative statement, “What's our first guess?... think about it, are there more pollinators in the prairie, on the lawn? What’s one of the possible answers?”

Example 3: In whole-group discussion on day eight of the Pollinator unit, Mr. Logan used the previous year's whole-class investigation poster for how to use the slides template to create a scientific poster to communicate findings from their small-group investigations (*Obtaining, Evaluating, And Communicating Results*). As he introduced each part of the poster, he covered up sections of the poster and thought aloud about what it meant and then asked students to think about what content they thought was appropriate for those sections. As consensus of the class thinking, they checked the content on the poster and discussed any discrepancies or questions.

Example 4: The final project was the small-group investigations. For this example, whole-class discussion was limited to announcements at the beginning and end of class to help students measure their rate of progress.

For RQ1, *how do elementary students engage in the practices of science while conducting an inquiry investigation (a) whole-class interactions, (b) peer-to-peer interactions, and (c) written artifacts in science notebooks and posters?* is whole-class discussion supports students in inquiry instruction by using multiple examples of scientific inquiry investigations. By delving into four investigation examples, students have **multiple experiences** to use the POS which is especially important for elementary students with limited experience using independent investigations in **whole class discussion**. The emphases in these statements on multiple experiences and the whole-class discussion settings are intentional as these two features supported novice investigators. First, I describe the findings relative to multiple examples of investigations.

Provides multiple examples of investigations. Whole-class discussion was the format for introducing and modeling the use of scientific language conventions for students. The repeated exposures to different investigations allowed students to gain familiarity and increased comfort level with the POS in a relatively short time. Modeling with multiple investigation examples was an effective strategy to show students how to make decisions using teacher think-aloud while making new discoveries in these authentic investigations. Real-world contexts allowed students to engage in scientific problem-solving instead of learning by memorizing scientific facts (Grant et al., 2012).

Balancing student independence in whole-class discussion. Inquiry instruction promotes student independence to design their own questions, processes, and solutions. Teachers are challenged to provide the necessary background supports in the POS and in disciplinary content knowledge in this unstructured setting. Mr. Logan moderated this challenge by providing a balance of direct instruction in whole-class discussion and independent practice in peer-to-peer discussion.

In whole-class discussion, Mr. Logan set the purpose of the lesson, provided guided instruction to jump-start student thinking, demonstrated new skills through modeling, thought aloud about decisions made in the demonstration, provided prompts to help students apply what they already knew, and made connections to new learning. Educational modeling, another term for focused instruction, is a practice distinct from modeling in the practice of science, *Designing And Using Models*. In educational practice, "...modeling is an aspect of direct instruction that should be followed by

structured and scaffolded practice and a gradual release of responsibility to support increasingly independent practice” (Maynes, Julien-Schultz, & Dunn, 2010, p. 66).

Mr. Logan used scaffolded instruction to build a structure (scaffold) to provide support for students which allowed them to extend the reach of their learning, connecting back to the theoretical framework of socio-constructivism.

Implications for science education using the POS

There are two relevant findings for science education and elementary science practitioners to provide frameworks for teaching the POS through inquiry investigations. First, using citizen science, whole-class investigations, and an example from the previous year’s class investigation were instructive to students to get familiarized with the POS and disciplinary core instruction. Metz (2008) discussed the importance of merging scientific practices with scientific content in what she calls the “bootstrapping principle... to capitalize on the interconnectedness and potential synergy of process and content knowledge” (p. 143). The intention was to provide opportunities to engage in POS in scientific content areas in which students have robust background knowledge.

Secondly, direct instruction during whole-class discussion created a structure for teaching inquiry by helping teachers find a balance between unstructured/independent instruction to structured/guided instruction. Colley and Windschitl (2016) report that most science instruction takes place in whole-class discussion with the teacher explaining content despite the need to increase student “productive talk” (p. 1010) to construct explanations and give reasons from evidence. Colley and Windschitl found that students engaged in more rigorous talk when the teacher used more than one of the six teacher-

mediated conditions (Cooley & Windschitl, 2016). Similarly, Mr. Logan played a pivotal role in the whole-class discussion, using three teacher-mediated conditions. 1) He used open-ended questions such as, who will benefit from this study? 2) he prompted students Jack and Lena, to explain their comments about why pollinators would be in the prairie where there were more flowers, and 3) he pointed to a representation, the whole-class investigation presentation slide listing the multiple hypotheses, to prompt Jack and Lena to how to present their work.

Group C worked together to construct explanations with each student taking responsibility to identify one explanation. Students were working on thinking of as many explanations as possible without connecting to a scientific explanation until Mr. Logan intervened and asked them to consider why pollinators would be more attracted to the woods than the prairie. This resembled findings from research in inquiry-based instruction that showed without some guidance from the teacher as to what science content or ideas the students should be learning, the elementary grade students generally get distracted by activities and miss the science they are supposed to learn (e.g. Upadhyay & Defranco, 2008). Teachers were also worried they weren't preparing their students for college, and that they weren't "covering" all the material (Minner et al., 2010; Upadhyay & Defranco, 2008; Anderson, 2002). Therefore, in this case Mr. Logan's intervention was essential to ensure desired science learning outcomes.

Claim 2: Peer-to-peer discussion promoted student engagement in scientific discourse. Students engaged in the POS in the peer-to-peer discussion setting more than any other setting, a product of the intervention curriculum and Mr. Logan's enactment of

the intervention curriculum itself. Fourth-graders demonstrated their capacity to engage in the POS tasks in small groups to develop questions, plan and carry out investigations, analyze data, and construct explanations. Furthermore, this environment also shows that elementary students are capable of engaging in authentic investigation confirming a similar finding from Duschl et al., (2007) .

As described earlier, the intervention curriculum emphasized student development of authentic testable questions and these questions were the backbone of the investigations and POS instruction. Accordingly, *Asking Questions and Defining Problems* was the most common POS employed in peer-to-peer discussion. For example, when examining questions and ‘I wonder’ statements to categorize questions, Lena recognized Tre’s question, “I wonder what kinds of bees live in our prairie,” as an example that met the criteria for a testable question. In this case and others, the small group setting allowed peers to share the responsibility for categorizing questions and learn from the shared ideas of the peers.

Students *Planned And Carried Out Investigations* overwhelmingly in the peer-to-peer discussion as they discussed the best ways to collect data and create data collection documents. By planning the investigation together, group members learned how they would collect data and prepare to carry out the investigation. Group C worked out the length of data collection in the observation, decision for the placement of the square-meter tool randomly, and clarification of the schoolyard locations for the observations. They also refined the purpose of their investigation when Sara said they would “check”

on the square meters and Ayana asked for clarity about what “check” meant for the investigation. Sara amended this term to “count the number of pollinators.”

Collaborative learning was an important setting for students to learn the conventions in the online template for *Obtaining, Evaluating, and Communicating Information* as they confirmed the expectations of each other. When the science unit ended, students completed these presentations in independent practice for a writing class project. The collaborative learning helped students ask questions and begin the presentation in a less threatening setting with peer support.

While students shared their questions with peers, they applied their learning about what made a testable question and some provided feedback to the questions. Peers used prompts to remind peers about safety constraints for example when Sara reminded a fellow peer about safety rules about eating pollen to test possible benefits of pollen for humans. Collaborative groups were powerful settings for planning the details of an investigation and enacting them. Group C students discussed the details of how they would randomly choose the one-meter-square plot to observe for pollinators. They were able to clarify confusion about terms used and discussed ways to avoid problems, like tossing the meter-square tool into a tree.

Two months after completing their investigations, a sample of Mr. Logan’s students participated in a science fair where they engaged in scientific communication to present their study (Appendix H) to their peers, answering questions from their scientists and peers, and asking questions on other peers’ investigations. This participation demonstrates their increased capacity to engage in scientific discourse.

The nature of scientific knowledge construction is inherently social, because scientists frame questions and present explanations based on evidence (Metz, 2008). A high incidence of discussions in the class while learning science shows that enacting the POS supported what the National Research Council (2013) suggested: “engagement in practices is language intensive and requires students to participate in classroom science discourse” (p. 50).

Implications for science education in inquiry instruction using the POS.

Peer-to-peer discussion is an important context for inquiry instruction as students enact the POS. Small group interaction provided more opportunities for students to speak and use the language of science. Peer-to-peer discussion was a nonthreatening environment with less competition for students to share their ideas.

RQ2. What practices of science are observed in (a) whole-class interactions, (b) peer-to-peer interactions, and (c) written artifacts in science notebooks and posters during an inquiry investigation?

Claim 3) Student engagement in the practices *Asking authentic Questions* *And Defining Problems* and *Planning And Carrying Out Investigations in familiar settings* facilitated their introduction into scientific dispositions and habits of mind in all three settings.

In this inquiry investigation unit, fourth graders demonstrated their capacity to complete independent investigations based on student-generated questions and to exhibit scientific dispositions and habits of mind especially in the practices of science *Asking questions And Defining Problems* and *Planning And Carrying Out Investigations*. These

two practices occurred at the beginning of the investigations and were critical to setting students for success. Allowing students to generate their own questions based on their schoolyard observations increased student engagement in the investigation. In the next section, I provide examples from each of the three settings, peer-to-peer discussion, whole-class discussion, and written artifacts.

***Whole-class discussion.** Planning and carrying out investigations.* Before students planned an investigation for the whole-class investigation, they practiced designing investigations based on questions presented by Mr. Logan in a class discussion on the sixth day of the unit. The class considered how to plan an investigation to find out if there were more goldenrod plants near the trail or away from the trail. Mr. Logan asked Ayana whether she had an idea about how to design the investigation.

Ayana: I think maybe that you could go over by the trail and count.

Mr. Logan: I'm worried that wouldn't be fair. You've got to make it really fair for the goldenrod near the trail and away from the trail. So, should I keep track of how long [the time] of the observation is? Why do I keep track? Why would I keep track of how long I was in both [locations]?

Ayana: Fair to both areas.

Mr. Logan: Both areas, yeah, that's a great word. And would it be fair if I was walking near the trail and [let's say] Student 5's a flower, and I think I see a bee [on him], do I write it down? [Mr. Logan continues by asking if it would be fair if he wrote down every pollinator he saw anywhere in the schoolyard no matter how far it was from him and the trail.]

Ayana: No.

Mr. Logan: What would make it fair as far as the area? Or does it matter about when I'm looking and about where I'm looking?

Ayana: You could use the [meter] squares.

Mr. Logan: And why does that, why does that square meter make it fair?

Ayana: ...because you put the square right by the trail and not by the trail.

Mr. Logan: Right

Ayana: And then the time's the same.

The scenario continues with Ayana and Mr. Logan agreeing that both the size of the space and the length of the observation need to be the same near the trail and away from the trail. Mr. Logan defined the word, variable and told, "that's called controlling a variable and you want to control as many as possible to keep it fair. [That's] good science, and the only thing that will be different is the area."

This excerpt illustrates an example of Mr. Logan supporting students through controlling variables and fair testing in the planning and carrying out the investigation. Ayana shows she has learned from a previous investigation how the square meter tool is used to plan a fair investigation. These conversations and the gradual introduction of scientific tools supported students to use them in small-group investigations later in the unit showing students' development of scientific thinking and skills to show their development of scientific habits of mind.

Peer-to-peer discussion. *Asking questions And Defining Problems* The small group conversation recorded in the following excerpt, Group A, included four students

named Joy, Lena, Iris, and Tre who read through their questions and choose one of the four question types for their question. Tre had a special education assistant working with him and the assistant acted as his spokesperson in this excerpt.

Lena: So, one of mine is how much pollen can a bee carry? I think, I don't really know, do you think you can look that one up?...

Iris: I think you could look that up or ask an expert.

Lena: Ms. Mary [Researcher], we're wondering how much can a bee carry...

Researcher: Yeah, how would you test that...

Lena: We'd take like the pollen- would you do something where you take the pollen off? I might want to do that one when I'm older cause it would take a long time.

In this excerpt, Lena demonstrates interest and commitment to a scientific endeavor when she projects that she needs more expertise and time to pursue one of her proposed questions.

In the following excerpt, Group C (Sara, Serena, Anaya, and Mark) was counting the number of pollinators in the woods and in the prairie to determine which habitat had the most pollinators. As their pollinator count was wrapping up, Anaya checked in on the results.

Anaya: How much did we get for the woods?

Sara and Mark: We had 13 beetles and four others...

Mark: The prairie might actually lose...

Students continued to observe and then after three more minutes return to the discussion about which habitat had the most pollinators.

Mark: The prairie's going to get beaten.

Anaya: Yeah, I didn't think that. I thought that maybe the woods might win, but I thought the prairie would win from my last time here.

While students were collecting data, they began to discuss with each other in their small group whether the woods or prairie habitats would “win” demonstrating their investment in and awareness of the meaning of the investigation results.

Written artifacts. In the case of Mr. Logan's classroom, students' written artifacts during the Pollinators unit documented their observations and questions and their data collection. Students' independently-written artifacts demonstrated their thinking about the Pollinators unit and the POS. In other words, the written artifacts were used to engage in the POS rather than create a culminating document to represent the investigations or the unit.

Emphasis on authentic, student-generated questions and contributing data to a citizen science project. The intervention curriculum emphasized conducting investigations based student-generated questions which required strong student support to choose and develop a testable question. As students developed testable questions, they “use[d] argumentation to listen to, compare, and evaluate competing ideas and methods based on their merits” (NRC, 2013, p. 396). After peer-to-peer discussion, students discussed, as a whole-class, why they had classified questions as “look-it-up”, “too big”, or “testable” and used argument to defend the reasoning for their classification. Students

build their capacity to handle the POS by investigating a meaningful question and increasing student engagement and investment in the results of the study. The study affirms the ability of fourth-graders to construct knowledge about the pollinators in their schoolyard and debunk ideas that relegate authentic studies to older students (Miller et al., 2018). In the following quote from direct instruction, Mr. Logan framed the citizen science project as a model for doing science.

The citizen scientist project does feel different than doing normal schoolwork because we actually get to provide information to the scientist that'll actually provide data that could help figure out why the bee population was declining.
(Classroom observation, 9/13/18)

Mr. Logan's summary served to review the goal of the citizen science project and explicitly pointed out how collecting and reporting data to a scientist's database is different from "normal schoolwork" in which the results are used only for classroom purposes.

Implications and Future research

Explore options for increasing rigor in scientific discussion/ scientific background knowledge for increased scientific rigor. In the case of a fourth-grade classroom with limited prior knowledge of the POS and pollination indicates that teachers could use a combination of direct instruction and inquiry instructions depending on students' knowledge about POS and content. Additionally, teachers could focus more on developing strategies that help guide students to apply science concepts and engage in

scientific thinking. This case shows that teachers could use multiple contexts such as insects, prairies, and weather to make learning POS more authentic to what scientists do.

An important implication of this study is that multiple modes of class interactions supports better experience and learning of POS. Science teachers could benefit more by increasing the quantity and quality of teacher-student and peer-to-peer interactions in helping students build POS skills. These interactions also promote complex connections between what students learned in science with other contents and contexts. Peer-to-peer interactions generates greater benefits to learning POS, therefore, teachers should consider adding more of these opportunities.

Teachers and teacher educators would benefit from analyzing the rigor of teacher-talk actions during whole-class discussion using measures similar to Cooley and Windschitl's (2016) teacher-mediated actions scales. Additionally, students need to adopt more strategies to engage in productive talk to deepen their scientific explanations and argumentation in small group settings as currently, the research emphasizes argumentation in written work in whole-class settings. Future research initiatives are needed to identify frameworks to increase the rigor of scientific student talk in small group discussions.

Maximizing options for tapping into funds of knowledge. For future research, great potential exists to maximize opportunities of the POS for English learners (EL) and students from nonwhite cultures through the use of authentic settings and students' funds of knowledge. Integrating authentic settings when engaged in the POS increases

relevance and student engagement, and potentially taps into students' funds of knowledge and increases cultural responsiveness (Lee, Miller, & Januszyk, 2014).

Laurer and Schauble (2006) advocate for providing authentic learning settings to increase student learning. Additionally, using authentic settings in science promotes tapping into students' cultural funds of knowledge and prior knowledge in "connected science" improving long-term retention (Upadhyay, 2008) as students build on their previous life experiences. Teachers assume responsibility for guiding whole-class discussion and need to be cautious about projecting their ideas, rooted in their sociocultural backgrounds, for the classroom, thereby unintentionally silencing students from different sociocultural backgrounds (Miller et al., 2018).

Language integration in Science Learning. One of the implications of this study is that teachers need to find ways to support students who are EL. Since many practices of science require students to engage with their peers and teachers to engage in science effectively, teachers need to provide language supports to students. Providing sentence starters such as "I wonder..." etc. are ways through which teachers can support students. Without language support from teachers, students' learning of POS and subsequently participating in authentic science experience are less effective or even detrimental. For future research, great potential exists to maximize opportunities of POS for English language learners and students from EL groups through the use of authentic settings and students' languages. Another implication for teachers and curriculum is helping students to adopt more strategies to engage in productive talk to deepen their scientific explanations and argumentation in small group settings (Anderson et al., 2001).

The study reinforces the value of language in science instruction with respect to engaging in POS. Students experienced opportunities to use language to explain their thinking, develop reasoning skills, articulate their ideas, and learn to evaluate their peers' ideas, all within in an authentic citizen science context. These opportunities are especially valuable to English language learners (Lee, Quinn, & Valdes, 2013).

Overlapping nature of POS. This study clearly has implications to teaching science and designing and writing science curriculum because students engage in POS in a complex web. A POS does not exist alone but rather a POS is connected to another POS. Therefore, teachers need to design and enact their science curriculum in such a way that students have opportunities to experience several POSs in an overlapping manner. Science happens in a non-linear way so the POS need to be introduced to students not as a set of hierarchical skills but an intricate action taking place in a web-like process. Another implication of this study is for the teacher education programs where POS should be taught to preservice teachers so that they understand that POS is learned better when its presented as a non-linear process. Science education could benefit if researchers explored how pre-service teachers gain confidence in teaching POS as a non-linear process.

Conclusion

The significant findings from this study assert whole-class discussion supports students when using the POS in multiple iterations of scientific investigations, peer-to-peer discussion promotes student engagement in scientific discourse, and student engagement in the practices *Asking questions And Defining Problems* and *Planning And*

Carrying Out Investigations facilitated their introduction into scientific dispositions and habits of mind in all three settings.

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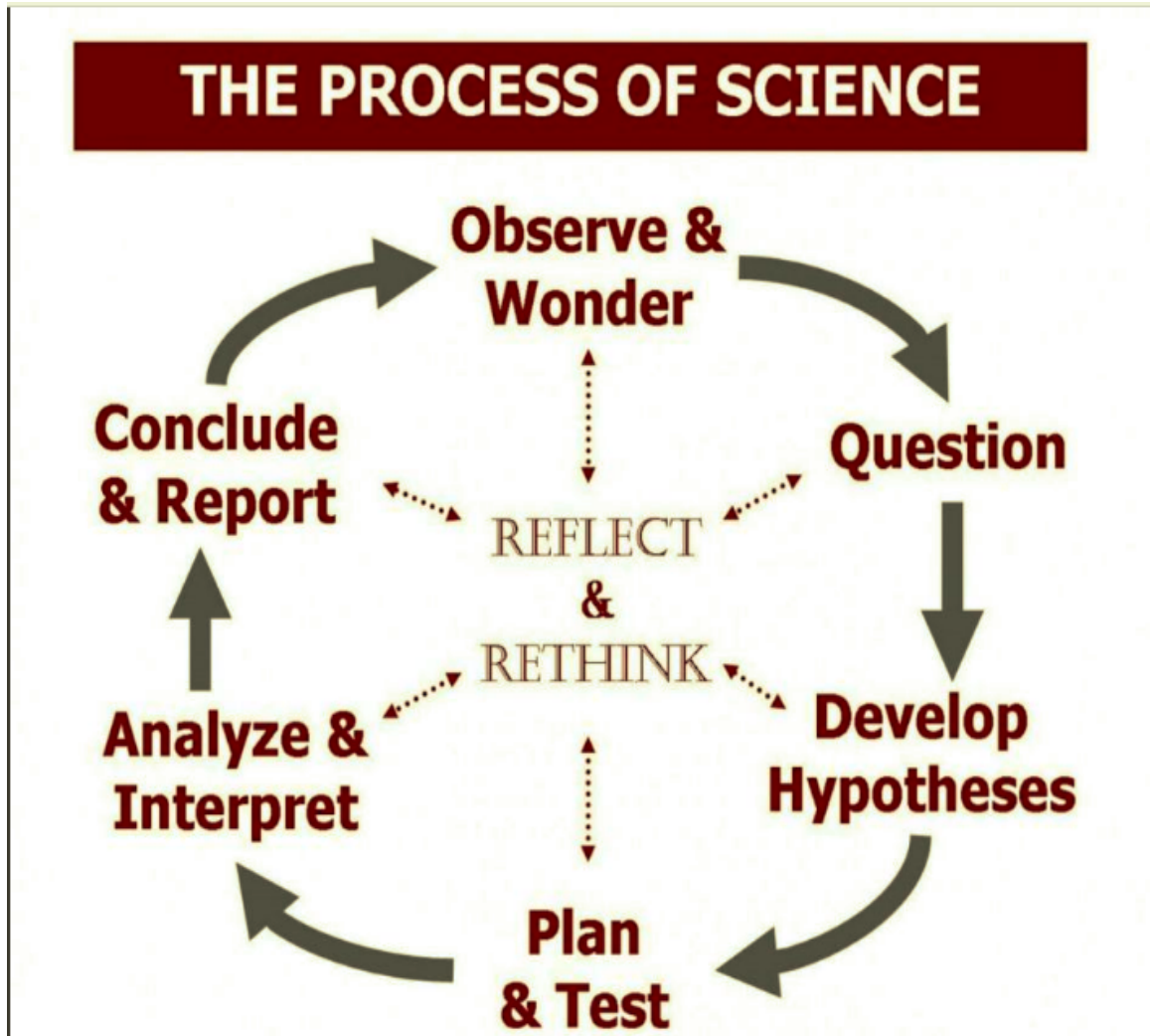
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Appendix A

Process of Science Wheel



Appendix B

Conducting Independent Investigations

After students are familiar with the science skills required to carry out their citizen science projects, and have collected and submitted data for these projects, they are ready to engage in their own research. You may do a single experiment with your entire classroom, or you may generate several questions tested by small groups.

The following activities are separated into lesson plans for each step depicted in Figure 1, but each lesson is not intended to fill a whole class period. You can decide how much class time to dedicate to each step as you work your way through the process. How long you spend on each step depends on your students' prior knowledge and your goals for your students. But it works best to follow the sequence in the order it appears.

The Driven to Discover materials are designed to support a largely verbal, interactive process intended to be engaging and thought provoking. Throughout the process, encourage students to record their ideas and decisions in a notebook or science journal. They will need to refer to these details when writing conclusions and preparing to share their findings.

The process of developing and implementing an investigation requires explanation and guidance at first. But once they learn the steps, your students will have the skills to design science investigations on their own.

OBJECTIVES FOR INDEPENDENT INVESTIGATIONS

- Students will conduct a scientific investigation based on observations and questions from their experiences as citizen scientists.
- Students will collect, analyze, and interpret data to formulate answers to a science question.
- Students will record notes about their planning

- process, data collection, and data analysis.
- Students will communicate their findings.

NGSS SCIENCE PRACTICES

- Asking questions
- Planning and carrying out investigations
- Analyzing and interpreting data
- Constructing explanations
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information



Encourage students to continue adding to the "I Wonder" Board throughout the research process.

THE PROCESS OF SCIENCE

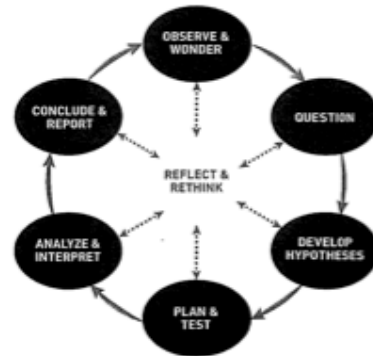


FIGURE 1. Scientific discoveries are made through the process of investigation, though scientists often use the word "research" or "the scientific method" to describe what they do. Investigations involve detailed examination of phenomena with the goal of discovering and interpreting new knowledge, whether the knowledge is new to humankind, to a small group of people, or just to the person doing the research.

MINI-INVESTIGATIONS

LESSON PLAN

OBJECTIVE

Students will practice steps in the process of doing science.

NEXT GENERATION SCIENCE STANDARDS

Science Practice 3: planning and carrying out an investigation

MATERIALS

- Mini-Investigation worksheet
- Pen/Pencil
- Supplies for specific investigation

OUTDOOR/INDOOR & TIME OF YEAR SUGGESTIONS

A mini-investigation can take place outdoors or indoors any time of year, but the investigations will be different based on these factors. Outdoor investigations can allow students to collect observational data if the season is right. For example, don't plan to observe pollinator behavior outdoors in winter; but, bird behavior is observable any time of year. Indoor investigations might focus on analysis of existing citizen science data.

TIME REQUIRED

1-2 class periods

PROCEDURE

The Mini-Investigation worksheet is designed to help you conduct a short investigation to give students a chance to practice the many steps in planning and carrying out an investigation. They are meant to be quick, collaborative, and fun! To expedite the process of developing an investigation, a question is provided to students.

1. Introduce the question.
2. Work with students to develop hypotheses based on the question provided.
3. Discuss how to test the question with a step-by-step plan for collecting data and making sure the process will result in fair, accurate data.
 - How will you collect data?
 - How much data do you need to collect?
 - What should data collectors do, look for, or count/not count so everyone is doing it the same way?
 - What materials will you need?
 - How will you record the data you collect? Make a data recording sheet.
4. Collect the data. Since this is meant to be a practice exercise, be sure to keep this fun while still working carefully.
5. Use the graph paper on the back of the Mini-Investigation worksheet to make a graph that represents the data you collected. Be sure to label the axes on the graph and give it a title.
6. Write a conclusion by answering the questions in the "Conclude & Report" box on the worksheet.
7. Discuss:
 - Which hypothesis was supported by our data?
 - How did our planning work make the data collection easier or harder?



Investigation photos by Ami Thompson

Mini-Investigation

CONCLUDE & REPORT

Summarize the results, including which hypothesis was supported by the study.

What did you learn by doing this investigation?

ANALYZE & INTERPRET

Describe the results of what happened. Use graph paper to make a chart to summarize your data.

OBSERVE & WONDER

AFTER INVESTIGATION
What observations made during your investigation have led to new questions?

REFLECT & RETHINK

PLAN & TEST

Create a step-by-step procedure for your investigation. Remember to think about materials, methods, sample size, and constants. Use graph paper to make a table to record data.



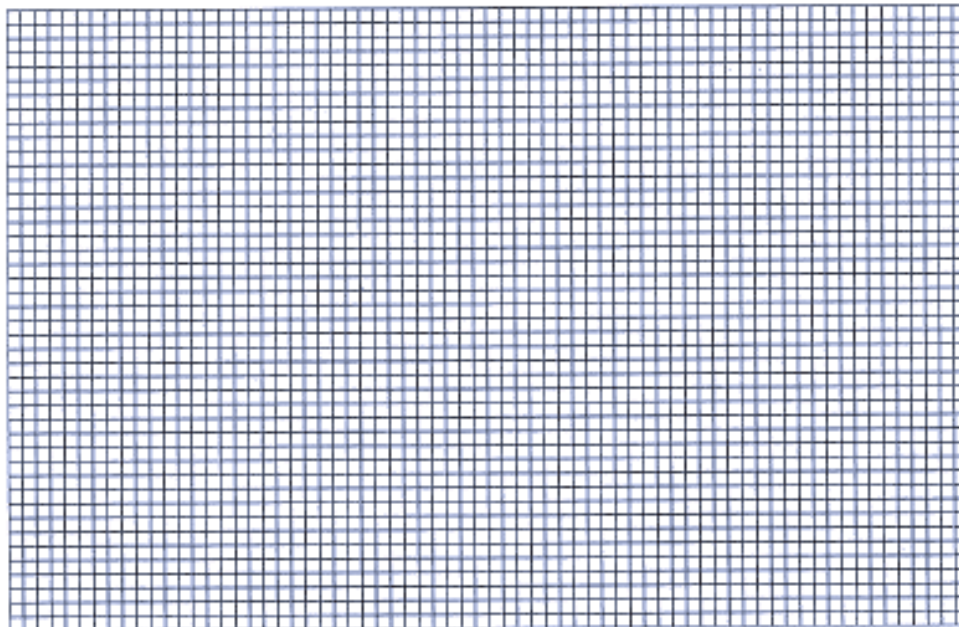
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DATA TABLE

Use this space to make a table to record data.

RESULTS

Use this graph paper to make a chart that summarizes your data.



Appendix C

CETP (REVISED) Core Evaluation

Context

Describe the context of the lesson in a couple of sentences

This lesson was devoted to finishing writing hypotheses for the questions the students chose to test and then spend time either setting up the experiment or begin observations.

Class Description and Purpose

A. Classroom Checklist

Type of Instruction

L	lecture/presentation	CL	cooperative learning (roles)
PM	problem modeling	LC	learning center/station
SP	student presentation (formal)	TIS	teacher/faculty member interacting w/ student
LWD	lecture with discussion	UT	utilizing digital educational media and/or technology
D	demonstration	A	assessment:
CD	class discussion	AD	administrative tasks
WW	writing work (if in groups, add SGD)	OO	out-of-class experience
RSW	reading seat work (if in groups, add SGD)	I	interruption
HOA	hands-on activity/materials	OTH	Other Please describe.
SGD	small group discussion (pairs count)		
Claims Evidence Reasoning	C: Claims E: Evidence REAS: Reasoning REB: Rebuttals	Scientific Inquiry	Information seeking or Investigative/Experimental Process: O: <i>Observations</i> Q= Questioning HY: <i>Hypotheses</i> development PLAN: <i>Planning</i> or <i>designing</i> the information gathering, experiment/field study DC: <i>Data collection</i> DA: <i>Data analysis</i> CONC: <i>Conclusion</i> COMM/P: <i>Communication or presentation of the results of</i>

			<i>inquiry</i> LU: Limitations and uncertainties NS: Next steps
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Student Engagement

LE: low engagement, 80% or more of the students off-task

ME: mixed engagement

HE: high engagement, 80% or more of the students engaged

Cognitive Activity

1 **Receipt of Knowledge** (lectures, worksheets, questions, observing, homework)

2 **Application of Procedural Knowledge** (skill building, performance)

3 **Knowledge Representation** (organizing, describing, categorizing)

4 **Knowledge Construction** (higher order thinking, generating, inventing, solving problems, revising, etc.)

0 **Other** (e.g., classroom disruption)

Time in minutes

	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45
Instructions									
Student									
Cognitive									
Inquiry									
Explanations									

Time in minutes

	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95
Instructions										
Student										
Cognitive										
Inquiry										
Explanations										

Describe the lesson you observed and its purpose

Observations notes:

0-5

5-10

10-15

15-20

20-25

25-50

50-60

Ratings of key indicators

In this section, you are asked to rate each of a number of key indicators as descriptive of the lesson in five different categories, from 1 (not at all) to 5 (to a great extent). Note that any one lesson may not provide evidence for every single indicator; use DK, “Don’t Know,” when there is not enough evidence for you to make a judgment. Use N/A, “Not Applicable,” when you consider the indicator inappropriate given the purpose and context of the lesson.

<ul style="list-style-type: none">o This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	1 2 3 4 5 DK N/A
<ul style="list-style-type: none">o Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.	1 2 3 4 5 DK N/A
<ul style="list-style-type: none">o Students were reflective about their learning.	1 2 3 4 5 DK N/A
<ul style="list-style-type: none">o The instructional strategies and activities respected students’ prior knowledge and the preconceptions inherent therein.	1 2 3 4 5 DK N/A
<ul style="list-style-type: none">o Interaction reflected collaborative working relationships among students (e.g. students working together, talking with each other about the lesson) and between teacher and students.	1 2 3 4 5 DK N/A
<ul style="list-style-type: none">o The lesson promoted strongly coherent conceptual understanding.	1 2 3 4 5 DK N/A
<ul style="list-style-type: none">o Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.	1 2 3 4 5 DK N/A
<ul style="list-style-type: none">o The teacher displayed an understanding of science concepts in his/her dialog with students.	1 2 3 4 5 DK N/A
<ul style="list-style-type: none">o Appropriate connections were made to other areas of mathematics/science, to other disciplines, and/or to real-world contexts, social issues, and global concerns.	1 2 3 4 5 DK N/A

Appendix D

Teacher interview questions

1. What would you like your pseudonym to be? (I'll ask again at the end or you can get back to me later if you want)
2. What do you consider when you select table groups?
3. What are the benefits to teaching science using the practices of science/inquiry investigations?
4. What are the drawbacks to teaching science using the practices of science/inquiry investigations?
5. Another way to think of that question: how do your grade level colleagues perceive this science unit as different to other science units?
6. How does this science unit compare and contrast with other science units?
7. What are specific areas in which you would like the lesson/s to go differently?
8. Since the investigation is considered part of the writing curriculum, describe how the unit fits into writing.
9. How do you think students perceive this unit, as writing, science, or both?
10. How does this work compare to students working in groups or doing independent projects in other content areas such as a writing project?
11. What would you like your pseudonym to be?

Appendix E

Hedenstrom dissertation codebook

How do elementary students engage in the practices of science while conducting an inquiry investigation? The supplemental research question is: *What practices of science are observed in (a) peer-to-peer interactions, (b) whole class instruction, and (c) written artifacts in science notebooks and posters during an inquiry investigation?*

Crawford (2012) uses this language “impact of inquiry-based instruction on student learning of science concepts, principles, and NOS”; Berland et al., (2015) use “epistemologies in practice: Making scientific practices meaningful for students”.

a=peer to peer student discourse

b=whole class student discourse and whole class teacher discourse

c=student written artifacts

Q	Theme	Code	Description	Definition
a	Argumentation	SCERP	Student practice of CER/argumentaton	Student using evidence to make connections to body of science, and make meaning verbally with peer/s in small group
a	Math	SMT	Students using math	Student using math and computational thinking; this includes formatting the graphs but does not include conversations about preferences such as which colors to use in the background and font.
a	Planning	SDPP	Student practice of developing science method	Student develops a procedure for a pollination investigation with peer/s in small group
a	Planning	SPPP	Student practice of performing science	Student performs a procedure for a pollination investigation

			method	with peer/s in small group
a	Planning	SPDCP	Student practice of science data collection	Student performance in talks with peers about collecting data and enacting their procedure
a	Constructing explanations	SPCP	Student practice of constructing explanations	Students verbally summarizing results, reflecting on what to do differently, developing implications, identifying audience, with peer/s in small group.
a	Analyzing	SPDAP	Student practice of science data analysis	Students discussing with peer/s about which hypothesis their data supports and compiling data
a	Asking	SPHP	Student practice of science hypothesis	Student generates investigation hypotheses with peer/s in small group
a	Asking	SOMP	Student observation or an “I wonder” statements	Student repeats or generates original observation or ‘I wonder’ statements with peer/s in small group a.articulating a misconception b.repeats teacher-presented or another student’s content c.accurately adds on to teacher-presented content d. Student makes original observation
a	Asking	SPQP	Student practice of science questioning	Student develops a testable question to lead an investigation with peer/s in small group
a	Modeling	SMOD	Student practice of making a model	Student working in small groups to make a model of their data using Google sheets

a	Communicating	SCOMP	Students creating a investigation poster	Students working in small groups to make a scientific presentation poster.
b	Argumentation	SCERW	Student practice of CER/argumentation	Student using evidence to make connections to body of science, make meaning in whole group discussion
b	Planning	SDPW	Student practice of developing science method	Student develops a procedure or part of a procedure for a pollination investigation in whole group discussion
b	Asking	SOMW	Student observation or an “‘I wonder’ statements”	Student repeats or generates original observation or ‘I wonder’ statements in whole group discussion
b	Communication	SPCOMW	Student responses to teacher instruction on making poster	Students discussing presentation content in whole group
b	Constructing explanations	SPCW	Student practice of constructing explanations	Student summarizing results, reflecting on what to do differently, developing implications, identifying audience, in whole group discussion
b	Data analysis	SPDAW	Student practice of science data analysis	Students discussing about which hypothesis their data supports in whole group discussion
b	Asking	SPQW	Student practice of science questioning	Student develops a testable question to lead an investigation in whole group discussion
b	Math	SWMT	Students discussing math in whole group	Students compiling results using math, asking questions about using math in the study

c	Argumentation	SCERPWr	Student practice of CER/argumentation	Student using evidence to make connections to body of science, make meaning
c	Modeling	SMDWr	Students using models in writing	Student labeling diagram of a flower and drawing prairie flower.
c	Asking	SOMWr	Student observation or an 'I wonder' statements	Student repeats or generates original observation or 'I wonder' statement in writing a. I wonder b. Testable question c. Adding on or deepening student ?
c	Planning	SPDCWr	Student practice of science data collection	Student developing data collection sheets.
c	Math	WMT	Student using math	Student writing using tally sheets to count pollinators

Appendix F

Writing a conclusion for student investigations

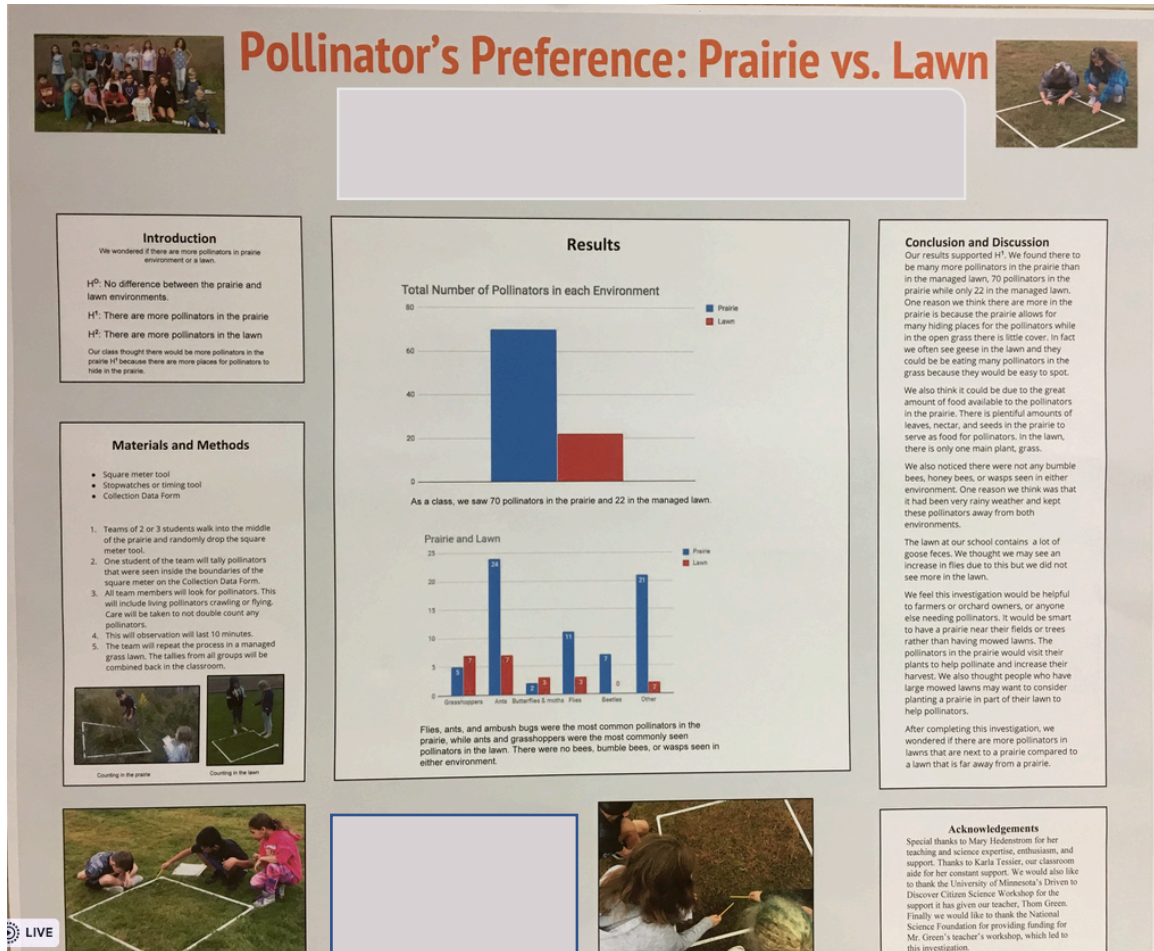
1. Which hypotheses did your investigation support? Did it support two hypotheses?
2. Brainstorm as many reasons as possible, why was that hypothesis supported?
Things to consider: did it support it because it was in a different location, did it support it because of something to do with the weather or maybe both, did it support because of the difference in your flowers you were looking at if you were looking at flowers? did it support it because of the difference in the type of pollinators? Or how you collected your data?
3. Was there anything that surprised you? Why?
4. If you were doing this again what would you do different currently?
5. Who would this investigation be helpful for and why?
6. What wonders do you have after doing your investigation?

Previous Year's Investigation Poster



Appendix H

Current Year's Whole-class Investigation Poster



Appendix I

Teacher-generated Investigation Questions

- How does the number of pollinators in the flower garden compare to the number of pollinators in the prairie?
- Are there more pollinators on the goldenrods in the prairie or on the goldenrods outside of the prairie?
- How does the number of bees on goldenrods compare to the number of other pollinators on the goldenrods?
- Are there more bees or wasps visiting the goldenrods?
- Are there more honey bees or bumble bees visiting our goldenrod?
- How different is the soil temperature in different environments?
- Are there more pollinators in the forest area or prairie?
- Are there more pollinators on a yellow flower or green plant?
- Are more pollinators attracted to a fruit or a goldenrod?
- Are there more pollinators on the wood chips on the playground or in the forest?
- Are there more pollinators in the middle of the prairie or on the edge of the prairie?

Appendix J

Current year's small-group Investigation Poster

